

# A Review of the Global Burden of Antimicrobial Resistance: Trends, Challenges, and Future Directions

<sup>1,2</sup>Moses Adondua Abah, <sup>3</sup>Jilume Jane Uba, <sup>2,4</sup>Micheal Oladosu Abimbola, <sup>5</sup>Odoh Emeka Hyginus, <sup>6</sup>Kingsley Chimuanya Umezurike, <sup>7,8</sup>Adetoyi Gbadebo Moses, and <sup>1,2</sup>Ochuele Dominic Agida

<sup>1</sup>Department of Biochemistry, Faculty of Biosciences, Federal University Wukari, Taraba State, Nigeria

<sup>2</sup>ResearchHub Nexus Institute, Nigeria

<sup>3</sup>Department of Human Anatomy and Forensic Anthropology, Faculty of Basic Medical Sciences, Cross River State University, Cross River State, Nigeria

<sup>4</sup>Department of Chemical Sciences, Faculty of Science, Anchor University, Ayobo, Lagos State, Nigeria

<sup>5</sup>Department of Biology, Faculty of Arts and Sciences, Georgia State University, USA

<sup>6</sup>Department of Medical Microbiology and Public Health, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria

<sup>7</sup>Department of Medical Biochemistry, Faculty of Basic Medical Sciences, College of Health Sciences, University of Ilorin, Kwara State, Nigeria

<sup>8</sup>Department of Chemical Pathology and Immunology, Faculty of Basic Clinical Sciences, College of Health Sciences, University of Ilorin, Kwara State, Nigeria

## Abstract

Antimicrobial resistance (AMR) poses a critical and escalating threat to global health, undermining the effectiveness of drugs used to prevent and treat infectious diseases. Driven by adaptive mechanisms in microorganisms, AMR compromises the efficacy of standard treatments, elevating the risks of disease spread, severe illness, and mortality. Recent estimates indicate that bacterial AMR was directly responsible for 1.27 million deaths globally in 2019, with a disproportionate burden in low- and middle-income countries (LMICs) due to limited access to diagnostics, effective antimicrobials, and resilient healthcare systems. The emergence and spread of AMR are propelled by multifaceted factors, including inappropriate antimicrobial use in human medicine and agriculture, inadequate infection control, environmental contamination, and weak regulatory frameworks. Socioeconomic determinants such as poverty, poor education, and limited healthcare access further exacerbate misuse and resistance, particularly in LMICs. Despite increased global recognition and the implementation of initiatives like the WHO Global Action Plan, persistent challenges remain in surveillance, measurement, and coordinated response. Many countries face infrastructural and operational limitations that result in fragmented and incomplete data, hindering effective policy development and intervention. AMR imposes significant clinical, economic, and social burdens, including increased morbidity and mortality, higher healthcare costs, reduced workforce productivity, and widening health inequities. Current response strategies emphasize antimicrobial stewardship, infection prevention and control, and multisectoral policy frameworks, yet disparities in implementation and resource allocation persist. Future priorities call for strengthening global surveillance, fostering innovation in antimicrobial development, enhancing diagnostic and stewardship technologies, and promoting integrated One Health approaches that address the interconnectedness of human, animal, and environmental health. Sustained investment, cross-sector collaboration, and global equity are essential to effectively mitigate the AMR crisis, preserve antimicrobial efficacy, and protect public health for future generations.

**Keywords:** Antimicrobial resistance, Global health burden, Drug-resistant infections, Surveillance, Epidemiology, and Public health policy

**Corresponding Author:** Moses Adondua Abah  
ResearchHub Nexus Institute, Nigeria

## INTRODUCTION

Antimicrobial resistance (AMR) is a growing global health threat that undermines the effectiveness of antimicrobial agents used to prevent and treat infectious diseases. It arises when microorganisms including bacteria, viruses, fungi, and parasites develop adaptive mechanisms that reduce or eliminate susceptibility to antimicrobial drugs, rendering standard treatments ineffective and increasing the risk of disease spread, severe illness, and death [1]. AMR poses a threat to the fundamentals of contemporary medicine by endangering standard clinical procedures that rely on efficient infection prevention and control, such as organ transplantation, cancer chemotherapy, surgery, and neonatal care [2]. AMR has grown to be a significant barrier to attaining global health security as resistance spreads among pathogens and geographical areas, especially in situations with minimal resources where surveillance and treatment options are still restricted [3].

The global burden of AMR is substantial and continues to rise. A landmark systematic analysis estimated that bacterial AMR was directly responsible for approximately 1.27 million deaths globally in 2019 and contributed to nearly 5 million deaths overall, making it one of the leading causes of mortality worldwide [4]. The burden is disproportionately concentrated in low-and-middle-income countries (LMICs), where limited access to diagnostics, effective antimicrobials, and resilient health systems exacerbates preventable morbidity and mortality [1, 4]. The disparity between global estimations and localized realities is further highlighted by empirical evidence from LMICs, which shows substantial resistance rates among prevalent clinical infections [5]. AMR has serious financial consequences in addition to its negative effects on health, as seen by longer hospital admissions, higher healthcare expenses, lower worker productivity, and restrictions on economic growth, all of which jeopardize the achievement of sustainable development goals [6].

The emergence and spread of AMR are driven by complex and interconnected factors operating across human, animal, and environmental systems. Inappropriate and excessive use of antimicrobials in human medicine, livestock production, and agriculture remains a dominant driver, accelerating selective pressure on microbial populations [7]. The spread of resistant organisms and resistance genes is further aided by poor infection prevention and control, poor sanitation, the distribution of subpar and counterfeit medications, and environmental contamination from pharmaceutical waste and water systems [2, 7]. According to Julius *et al.* [8], environmental surveillance investigations have increasingly found

resistant bacteria in sources of drinking water, supporting the idea that the environment is a crucial reservoir for One Health.

Despite increasing recognition of AMR as a global priority, major challenges persist in surveillance, measurement, and coordinated response. Many countries lack comprehensive laboratory capacity and standardized reporting systems, resulting in fragmented and incomplete data that obscure the true magnitude of the AMR burden [1]. Variability in surveillance methodologies and limited representation from resource-constrained settings further complicate cross-country comparisons and evidence-based policymaking [4]. Reviews focusing on global and regional AMR responses highlight persistent gaps in diagnostics, data integration, and multisectoral collaboration, particularly in LMICs [3]. While international initiatives such as the WHO Global Action Plan on Antimicrobial Resistance have strengthened political commitment, implementation remains uneven due to financial constraints, limited technical capacity, and governance challenges.

This review aimed at providing a comprehensive and integrated synthesis of the global burden of antimicrobial resistance, with a particular focus on epidemiological trends, systemic challenges, and future strategic directions. First, it examines current global and regional patterns of AMR-related morbidity and mortality, highlighting disparities across income levels, geographic regions, and health system capacities. Second, the review analyzes the major drivers and determinants of AMR, including antimicrobial misuse, environmental pathways, and structural weaknesses in healthcare delivery, regulation, and surveillance. Third, it critically evaluates current methods for measuring and tracking antimicrobial resistance (AMR), pointing out significant data gaps and methodological flaws that impede precise burden estimation and efficient policy development, especially in low-and-middle-income nations. Fourth, the evaluation assesses the efficacy, scalability, and equality implications of current national and international response options, including antimicrobial stewardship programs, infection prevention and control measures, and regulatory frameworks. The review concludes by discussing potential future approaches to the AMR crisis, with a focus on developing innovative antimicrobials, improving diagnostic and surveillance technologies, and implementing integrated One Health strategies that acknowledge the interdependence of environmental, animal, and human health. This review aims to educate academics, clinicians, and policymakers by bringing disparate pieces of information together into a logical analytical framework. It also emphasizes the need for

consistent, coordinated international action to address one of the biggest risks to the security of global health.

## GLOBAL BURDEN AND EPIDEMIOLOGICAL TRENDS OF ANTIMICROBIAL RESISTANCE (AMR)

Antimicrobial resistance (AMR) is recognized as one of the most significant threats to global health, compromising the effective treatment of bacterial, viral, and fungal infections worldwide. Resistant infections result in prolonged illness, increased mortality, and escalating healthcare costs, affecting both hospital- and community-acquired infections [2, 6, 7]. Systematic analyses indicate that AMR has become a leading contributor to the global infectious disease burden, underscoring the urgent need for robust monitoring and mitigation strategies [4]. In 2019, bacterial AMR was directly responsible for an estimated 1.27 million deaths and associated with nearly 5 million deaths worldwide [4]. Respiratory tract infections, bloodstream infections, and intra-abdominal infections account for the majority of these deaths [1]. Regional disparities are pronounced, with low- and middle-income countries particularly in sub-Saharan Africa and South Asia experiencing the highest mortality rates due to constrained access to effective antibiotics, diagnostics, and healthcare infrastructure [4, 9].

Epidemiological trends demonstrate a steady expansion of resistance across key bacterial pathogens. *Escherichia coli*, *Klebsiella pneumoniae*, *Staphylococcus aureus*, *Streptococcus pneumoniae*, and *Acinetobacter baumannii* consistently rank among the highest contributors to AMR-associated mortality, with increasing levels of multidrug resistance reported across diverse geographic regions [2, 7, 10]. Evidence from Nigeria highlights this growing

burden, with high resistance rates documented in *E. coli* isolated from both drinking water sources and clinical infections, illustrating the convergence of environmental and healthcare-associated transmission pathways [5, 8]. These findings reinforce the role of environmental reservoirs and community exposure in sustaining AMR circulation, particularly in settings with inadequate water, sanitation, and hygiene infrastructure.

The spread of resistance is driven by antimicrobial overuse, weak infection prevention and control, and environmental contamination, creating a dynamic and complex epidemiological landscape [6, 11]. Global surveillance initiatives, including the WHO Global Antimicrobial Resistance and Use Surveillance System (GLASS), provide standardized pathogen-specific data, revealing rising resistance to third-generation cephalosporins, carbapenems, and fluoroquinolones in both hospital and community settings [12, 13]. Analyses from the Global Research on Antimicrobial Resistance (GRAM) project further demonstrate shifts in AMR mortality over time, with declining pediatric deaths but increasing mortality among older adults, highlighting the influence of demographic transitions on AMR burden [4].

Collectively, these data underscore AMR as a multifactorial and escalating public health challenge. The global burden reflects persistent regional inequalities, pathogen-specific resistance patterns, antimicrobial use practices, environmental exposure, and evolving demographic risks. Understanding these interconnected trends is essential for informed policy formulation, strategic resource allocation, and prioritization of interventions aimed at reducing mortality, curbing the spread of resistant infections,

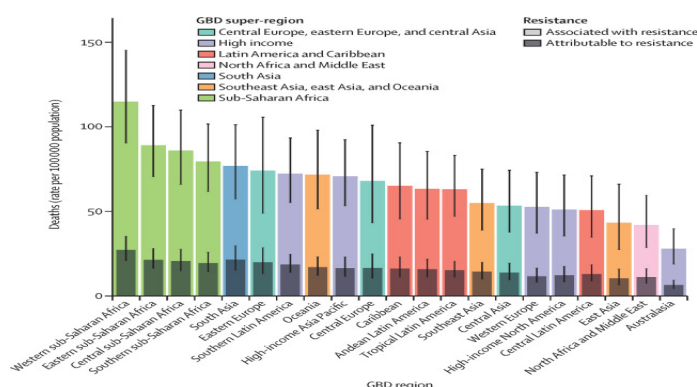


**Fig1.** All-age rate of deaths attributable to and associated with bacterial antimicrobial resistance by GBD region, 2019. The figure presents all-age mortality rates attributable to and associated with bacterial antimicrobial resistance across GBD regions in 2019. It highlights regional disparities, showing higher AMR-related deaths in low- and middle-income regions, reflecting differences in infection burden, healthcare access, and AMR management.

Source: [4]

and preserving antimicrobial effectiveness for future generations [9, 10, 11].

## MAJOR DRIVERS AND DETERMINANTS OF ANTIMICROBIAL RESISTANCE

Antimicrobial resistance (AMR) emerges from a constellation of biological, behavioral, socioeconomic,

and environmental factors. While the genetic capacity for microbes to adapt exists naturally, human activity accelerates the emergence and spread of resistance through selective pressure and ecological disruption [12]. Understanding the key drivers of AMR is critical to tailoring effective interventions across diverse global settings.

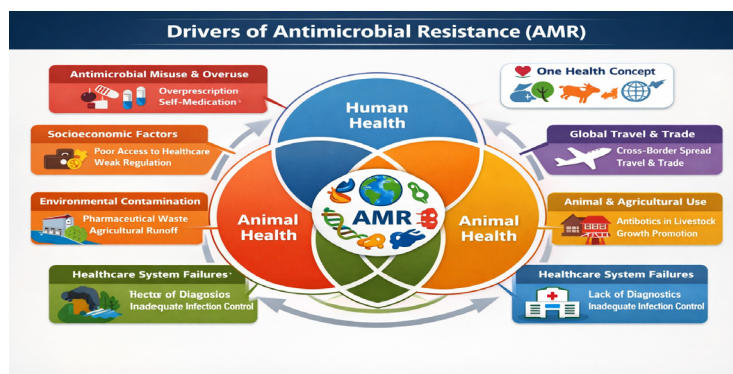


**Fig2.** Integrated One Health drivers and determinants of antimicrobial resistance (AMR). This figure illustrates the integrated One Health framework for antimicrobial resistance, showing how human, animal, and environmental factors interact to drive and sustain AMR. It highlights key determinants such as antibiotic use, infection control practices, agricultural practices, and ecological reservoirs, emphasizing the interconnected nature of AMR emergence and spread.

**Sources:** Modified from [12, 14, 15]

## MISUSE AND OVERUSE OF ANTIMICROBIALS

The primary driver of AMR is the inappropriate use of antimicrobials in humans, animals, and plant health sectors. In clinical settings, inappropriate prescription, over-prescribing, and empirical use without diagnostics create strong selective pressures favouring resistant organisms [12, 14]. Similarly, widespread non-therapeutic use of antibiotics in livestock for growth promotion and disease prophylaxis fosters reservoirs of resistant bacteria that can transfer to humans via direct contact or the food chain [14]. These practices intensify selective pressure within microbial communities and expedite the proliferation of resistant genotypes.

## SOCIOECONOMIC AND BEHAVIORAL DETERMINANTS

Behavioral and socioeconomic factors significantly shape antimicrobial use patterns and the spread of resistance, particularly in low- and middle-income countries (LMICs). Self-medication, ease of over-the-counter antibiotic access, and weak regulatory environments contribute to misuse, while limited public awareness and inadequate health infrastructure further exacerbate inappropriate consumption [15, 16]. Poverty, poor education, and financial barriers to healthcare often lead individuals to seek antibiotics without professional guidance,

reinforcing resistance trends. These determinants operate interdependently with cultural norms and healthcare access disparities, thereby shaping local and regional AMR profiles.

## ENVIRONMENTAL DRIVERS

Environmental pathways are increasingly recognized as pivotal conduits of AMR dissemination. Antimicrobial residues and resistant microorganisms enter ecosystems through untreated pharmaceutical wastewater, hospital effluent, agricultural runoff, and sewage, where they persist and exchange resistance genes with environmental microbiota [13, 14]. Aquatic systems can act as hotspots for horizontal gene transfer, facilitating the spread of resistance elements between environmental and pathogenic bacteria. Pollutants such as heavy metals and other biocides further exert co-selective pressure, promoting resistance even in the absence of direct antibiotic exposure.

## ONE HEALTH INTERCONNECTIONS

AMR is fundamentally a One Health problem, underscoring the interconnectedness of human, animal, and environmental health domains. Transmission dynamics extend beyond individual hosts to shared ecosystems, where resistant organisms circulate via food, water, and direct contact [12, 14]. The One Health framework highlights how intersectoral drivers including

international travel, trade, and cross-border livestock movement amplify the spread of resistance globally. Integrating surveillance and mitigation efforts across health, agriculture, and environmental sectors is therefore essential for comprehensive AMR control.

### SYSTEMIC AND POLICY INFLUENCES

Broader structural determinants, such as regulatory capacity, public health governance, and economic development, influence the trajectory of AMR. Countries with robust antimicrobial stewardship, surveillance, and

regulation demonstrate slower resistance proliferation, whereas fragmented policy environments facilitate unchecked use and distribution of antimicrobial agents [16]. Global inequalities in access to diagnostics and effective treatments further compound resistance by prolonging untreated infections and encouraging inappropriate antimicrobial use.

### SURVEILLANCE, MEASUREMENT, AND DATA GAPS IN ANTIMICROBIAL RESISTANCE

Robust surveillance and accurate measurement are

**Table 1.** Core drivers of antimicrobial resistance (AMR) in a One Health context

| Driver category            | Mechanistic Contribution to AMR                                                                                               | References |
|----------------------------|-------------------------------------------------------------------------------------------------------------------------------|------------|
| Human Antibiotic Use       | Inappropriate prescribing, self-medication, and poor adherence impose strong selective pressure for resistance                | [4, 12]    |
| Animal and Food Systems    | Routine antibiotic use in livestock establishes zoonotic and foodborne resistance reservoirs                                  | [11,14]    |
| Socioeconomic Determinants | Weak regulation, limited healthcare access, and informal drug markets drive misuse, especially in LMICs                       | [15, 16]   |
| Environmental Reservoirs   | Wastewater, agricultural runoff, and pharmaceutical effluents enable persistence and gene exchange of resistance determinants | [13, 14]   |
| Health-System Capacity     | Limited diagnostics, weak stewardship, and poor infection control accelerate resistance amplification                         | [4, 12]    |
| One Health Transmission    | Continuous circulation of resistant organisms across human-animal-environment interfaces sustain global spread                | [11, 13]   |
| Governance and Policy Gaps | Fragmented surveillance and weak enforcement undermine AMR containment efforts                                                | [13, 16]   |

foundational to effective antimicrobial resistance (AMR) responses, yet critical gaps persist in global systems for tracking resistance trends, antimicrobial use, and outcomes. Although international frameworks have advanced standardized data collection, many countries face structural and operational limitations that compromise the quality, completeness, and representativeness of AMR data. These challenges impede evidence-based policymaking and weaken capacity to monitor progress toward global targets.

### INCOMPLETE GLOBAL PARTICIPATION AND STANDARDIZATION

The World Health Organization's Global Antimicrobial Resistance and Use Surveillance System (GLASS) represents the most comprehensive global mechanism for AMR monitoring, providing standardized data on pathogen-antibiotic combinations and resistance prevalence. Despite substantial growth in participation with 104 countries reporting data in 2023, representing over 70% of the global

population nearly half of eligible reporting countries lack the infrastructure to generate reliable, comprehensive AMR data such as antimicrobial susceptibility testing (AST) with laboratory quality assurance, limiting global comparability and interpretation of trends [13].

### LABORATORY CAPACITY AND TECHNICAL BARRIERS

In many low- and middle-income countries (LMICs), deficiencies in laboratory infrastructure significantly constrain AMR surveillance. Studies reveal widespread shortages of trained personnel, inadequate diagnostic equipment, inconsistent access to quality reagents, and fragmented sampling practices, resulting in scattered and heterogeneous datasets that hinder accurate burden estimation [13, 17]. These technical barriers not only limit data generation but also reduce the ability of surveillance systems to detect emerging resistance patterns and support local clinical decision-making.

## FRAGMENTED DATA SOURCES AND INTEGRATION GAPS

Effective surveillance requires integration of data from human health, animal health, and environmental sectors, reflecting the One Health nature of AMR. However, existing systems often operate in silos, with inconsistent data standards, limited interoperability, and institutional fragmentation hindering cross-sector analysis and timely detection of resistance trends [18, 19]. The limited integration is particularly evident in veterinary and environmental AMR reporting, which remains underdeveloped compared with human health surveillance.

## GEOGRAPHIC AND DEMOGRAPHIC DATA GAPS

Despite improvements in national reporting, large regions including parts of sub-Saharan Africa, Central Asia, and Latin America remains under-represented or absent in global AMR datasets, leading to persistent blind spots in global estimates [20]. In these settings, surveillance often captures data only from tertiary referral hospitals or specialized laboratories, which may not reflect community-

level AMR burdens, undermining the accuracy of regional and global projections.

## SURVEILLANCE AND EMERGING GENOMIC SURVEILLANCE GAPS

Surveillance of antimicrobial consumption and use (AMU) is critical for understanding selective pressures driving resistance, yet standardized AMU metrics are sparsely reported or absent for many LMICs [13]. Without routine AMU data, linking resistance patterns to prescribing practices, stewardship effectiveness, or interventions remains challenging. These measurement gaps can mask emerging trends and impede targeted public health responses. Recent analyses also highlight significant deficiencies in genomic surveillance capacity, with large numbers of countries lacking publicly available pathogen genomes needed to track evolutionary dynamics of resistance [21]. Genomic data are increasingly crucial for early detection of novel resistance mechanisms and for informing rapid clinical and policy responses.

Overall, persistent gaps in surveillance infrastructure, laboratory capacity, cross-sector integration, and data

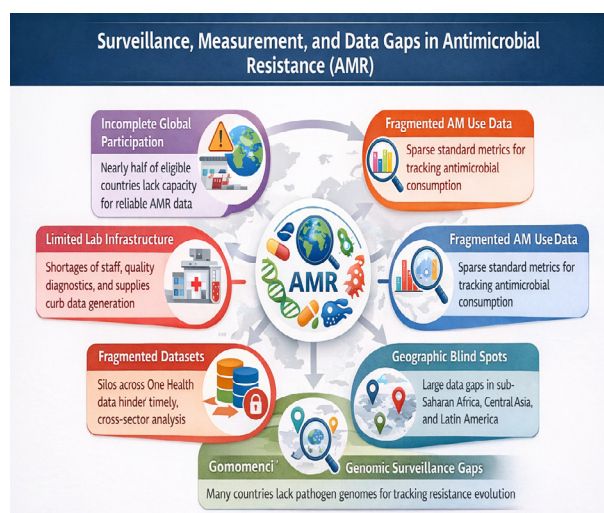


**Fig3.** Common challenges in antimicrobial resistance (AMR) surveillance systems. This figure summarizes the major barriers to effective AMR surveillance, including incomplete global participation, limited laboratory infrastructure, fragmented datasets, geographic blind spots, antimicrobial use monitoring gaps, and genomic surveillance deficiencies. Each element is interconnected, highlighting the One Health nature of AMR data challenges.

**Sources:** Modified from [13, 17, 19]

completeness complicate efforts to accurately measure AMR burden and trends. Addressing these challenges requires sustained investment in laboratory systems, standardized data platforms, and interoperable surveillance frameworks that align with One Health principles.

## IMPACTS OF ANTIMICROBIAL RESISTANCE ON HEALTH SYSTEMS AND SOCIETY

Antimicrobial resistance (AMR) imposes a substantial and multidimensional burden on clinical outcomes, healthcare systems, economic productivity, and social wellbeing. From

a clinical perspective, resistant infections are consistently associated with higher morbidity and mortality, as well as longer durations of illness and hospital stay compared with infections caused by susceptible organisms. A systematic review and meta-analysis found that resistant bacterial infections increased the average hospital stay by approximately 8.7 days and were associated with a 65% higher odds of mortality than susceptible infections, underscoring the severity of clinical impacts attributable to resistance [22].

These clinical burdens translate into significant strain on healthcare systems, including increased resource utilization and elevated treatment complexity. Drug-resistant infections often necessitate the use of more expensive, toxic, or second-line therapies, prolonged isolation and supportive care, and higher frequency of intensive care utilization, all of which amplify the workload and cost burden on hospitals and health services [23]. Moreover, resistant infections jeopardize the effectiveness of essential medical procedures such as chemotherapy, organ transplantation, and major surgeries, which rely on effective antimicrobials to prevent and treat secondary infections.

**Table 2.** Multi-dimensional impacts of antimicrobial resistance

| <b>I m p a c t s domain</b>    | <b>Specific effect</b>                                                                                                                                       | <b>References</b> |
|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|
| C l i n i c a l Outcomes       | Increased morbidity and mortality; longer hospital stays; complications from treatment failure; reduced efficacy of surgeries, chemotherapy, and transplants | [22, 23]          |
| Healthcare S y s t e m Burden  | Higher resource utilization: ICU admissions, prolonged hospitalizations, more complex treatments; strain on hospital capacity and infection control systems  | [24]              |
| E c o n o m i c Costs          | Direct healthcare expenditures; increased treatment costs; lost productivity from illness and disability; projected GDP losses                               | [24, 25]          |
| Social and E q u i t y Impacts | Disproportionate effects on low-resource populations; catastrophic household health expenditures; widening health inequities                                 | [25, 26]          |
| Population-Level Risk          | Threatens community health through transmission of resistant infections; amplifies vulnerability in LMICs and high-risk groups                               | [22]              |

morbidity in under-resourced settings. AMR can cause catastrophic health expenditures for households due to prolonged treatment and indirect costs such as lost earning potential, thereby reinforcing cycles of poverty and poor health outcomes [26].

## **CURRENT RESPONSES AND PERSISTENT CHALLENGES**

Global and national responses to antimicrobial resistance

Economically, the impact of AMR is profound at both local and global levels. Global modelling studies estimate that antimicrobial-resistant infections were associated with nearly US\$693 billion in hospital costs and almost US\$194 billion in productivity losses due to excess morbidity and mortality in 2019 alone, highlighting the extensive direct and indirect financial implications of resistance [24]. Beyond hospital costs, broader macroeconomic analyses project that continued unchecked AMR could reduce global gross domestic product (GDP) by a notable margin over coming decades as illness-related disability and premature death diminish labour market output and economic participation [25]. These projections indicate that AMR is not only a health issue but a systemic economic threat that can diminish household income, reduce national productivity, and exacerbate poverty especially in low- and middle-income countries where baseline health infrastructure and economic resilience are weaker.

At the population level, AMR amplifies health inequities. Socio-economic groups with limited access to quality healthcare are disproportionately affected by resistant infections, which contribute to higher mortality and

(AMR) have increasingly focused on antimicrobial stewardship (AMS), infection prevention and control (IPC), and supportive policy frameworks. Stewardship programs, implemented across hospitals and increasingly in community settings, aim to optimize antimicrobial prescribing, reduce inappropriate use, and preserve the effectiveness of existing drugs [27, 28]. Complementary IPC interventions, including hand hygiene, vaccination, environmental sanitation, and standardized infection

control protocols, mitigate transmission of resistant pathogens, particularly in high-risk hospital and long-term care settings [12, 29]. At the policy level, National Action Plans aligned with the WHO Global Action Plan encourage multisectoral collaboration across human, animal, and environmental health sectors, providing a One Health framework for AMR containment [29, 30].

Despite these advances, implementation barriers and inequities persist. Many low- and middle-income countries face limited financial, technical, and laboratory capacity to operationalize stewardship and surveillance programs, reducing the effectiveness of interventions [27, 29]. Disparities in policy enforcement, inconsistent regulatory oversight, and inadequate public awareness further exacerbate global inequities, leaving vulnerable

**Table3.** Summary of current AMR response strategies and persistent challenges across stewardship, infection control, policy, and public engagement domains, highlighting implementation gaps and inequities.

| Category                               | Key interventions                                                                      | Persistent challenges                                                        |
|----------------------------------------|----------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Antimicrobial Stewardship (AMS)        | Optimized prescribing, audit and feedback, education programs, community interventions | Limited coverage in LMICs, inconsistent implementation, variable adherence   |
| Infection Prevention and Control (IPC) | Hand hygiene, vaccination, environmental sanitation, standardized hospital protocols   | Resource limitations, gaps in training, inconsistent application             |
| Policy and Governance                  | National Action Plans, One Health frameworks, multisectoral coordination               | Weak enforcement, fragmented regulatory oversight, inequitable access        |
| Public Awareness and Education         | Mass media campaigns, stakeholder engagement, community outreach                       | Knowledge-practice gap, short-term interventions, socio-economic disparities |

populations disproportionately affected by resistant infections [12, 30]. Even in high-income settings, fragmented coordination across healthcare sectors and variability in compliance with stewardship and IPC guidelines can limit the impact of otherwise robust strategies. These persistent challenges highlight the need for sustained investment, capacity building, and equitable implementation of AMR interventions worldwide.

Modified from [12, 27, 29, 30].

## FUTURE DIRECTIONS AND STRATEGIC PRIORITIES

Addressing antimicrobial resistance (AMR) requires sustained, forward-looking strategies that integrate innovation, policy, and global cooperation. A critical priority is strengthening surveillance systems globally to

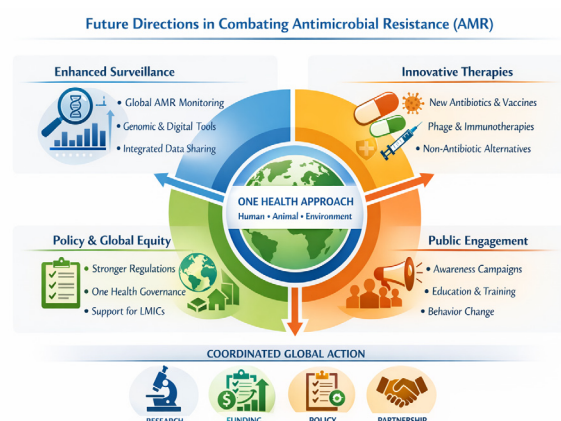


**Fig4.** Future directions and strategic priorities for combating antimicrobial resistance (AMR). The figure illustrates a One Health-centered framework integrating human, animal, and environmental health. Four key domains—Enhanced Surveillance, Innovative Therapies, Policy and Global Equity, and Public Engagement interact with the central AMR challenge. Coordinated global action in research, funding, policy, and partnerships underpins these strategies, highlighting the interconnected and multidisciplinary approach required to address antimicrobial resistance effectively.

monitor resistance trends, antimicrobial consumption, and emerging pathogens. Advanced genomic and digital health tools can enhance early detection, enable precision interventions, and guide antimicrobial stewardship programs [1, 4]. Integrating surveillance data across human, animal, and environmental sectors is essential to operationalize a One Health approach, which recognizes the interconnectedness of microbial ecology and resistance evolution [31].

Innovation in antimicrobial development and alternative therapies remains crucial. The current pipeline for new antibiotics is limited, particularly for multidrug-resistant Gram-negative pathogens, necessitating investment in novel chemical classes, phage therapy, immunotherapies, and vaccines to reduce infection incidence and reliance on traditional antibiotics [32]. Incentive mechanisms, including push-and-pull funding models, are needed to stimulate research while ensuring equitable access globally. Policy and governance reforms must emphasize global equity, cross-sector coordination, and enforcement of regulatory standards. Strengthening frameworks for antimicrobial use in humans, livestock, and agriculture, alongside harmonized international guidelines, can reduce unnecessary exposure and slow resistance emergence [1, 6]. Additionally, capacity building in low- and middle-income countries is vital to mitigate disparities in stewardship, infection control, and surveillance infrastructure.

Finally, public engagement and education should be sustained and context-specific, targeting prescribers, patients, and communities to promote responsible antimicrobial use. Multi-channel campaigns, integrated with local healthcare systems, have demonstrated effectiveness in shifting behaviors and fostering adherence to stewardship and infection control practices [27, 30]. Fostering a culture of shared responsibility at individual, institutional, and governmental levels is critical to long-term AMR containment.

## CONCLUSION

Antimicrobial resistance (AMR) represents a profound global challenge with wide-ranging consequences for human health, healthcare systems, and economic stability. The multifaceted nature of AMR spanning clinical, environmental, and societal dimensions—demands coordinated, multisectoral responses. Evidence indicates that effective stewardship, robust infection prevention and control, comprehensive surveillance, innovation in therapeutics, and policy integration are all critical to mitigating its impact. Yet, persistent gaps in implementation, inequities in resource allocation, and global disparities in access to effective interventions continue to hinder

progress. Looking forward, addressing AMR requires sustained investment, cross-sector collaboration, and the integration of One Health principles to ensure equitable and effective solutions. By combining strategic policy, scientific innovation, and public engagement, the global community can reduce the burden of resistant infections, safeguard the efficacy of antimicrobials, and protect population health for generations to come.

## Acknowledgement

We thank all the researchers who contributed to the success of this research work.

## Conflict of Interest

The authors declared that there are no conflicts of interest.

## Funding

No funding was received for this research work.

## REFERENCES

1. World Health Organization (WHO). Global Antimicrobial Resistance and Use Surveillance System (GLASS) Report 2023. World Health Organization. 2023. <https://www.who.int/initiatives/glass>
2. Prestinaci, F., Pezzotti, P. and Pantosti, A. Antimicrobial resistance: a global multifaceted phenomenon. *Pathogens and global health*. 2015; 109(7): 309–318. <https://doi.org/10.1179/2047773215Y.0000000030>
3. Gulzar, W., Suleman, M., Asif, S., Fazil, A., Ali, H. and Ahmad, M. Antimicrobial Resistance: A Review of Global Challenges and Collaborative Solutions. *European Journal of Microbiology and Infectious Diseases*. 2025. DOI:10.5455/EJMID.20250411054148
4. Antimicrobial Resistance Collaborators. Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. *Lancet* (London, England). 2022; 399(10325), 629–655. [https://doi.org/10.1016/S0140-6736\(21\)02724-0](https://doi.org/10.1016/S0140-6736(21)02724-0)
5. Shinggu, P. P., Imarenezor, K., Abah, M., Christian, I., Oladosu, M., Ajoniloju, M. et al. Antimicrobial Resistance Patterns and Immunological Electrolyte Profiling Among Pregnant Women with Urinary Tract Infections in Selected Local Government Areas of Taraba State, Nigeria. *Microbiology Archives, an International Journal*. 2025. DOI: <https://doi.org/10.51470/MA.2025.7.2.84>
6. O'Neill, J. Tackling Drug-Resistant Infections Globally: Final Report and Recommendations. Review on

- Antimicrobial Resistance. Wellcome Trust and HM Government. 2016. <https://www.scrip.org/reference/referencespapers?referenceid=2618400>
7. Holmes, A. H., Moore, L. S., Sundsfjord, A., Steinbakk, M., Regmi, S., Karkey, A. et al. Understanding the mechanisms and drivers of antimicrobial resistance. *Lancet* (London, England). 2016; 387(10014): 176–187. [https://doi.org/10.1016/S0140-6736\(15\)00473-0](https://doi.org/10.1016/S0140-6736(15)00473-0)
  8. Julius, S. O., Oladosu, M. A., Abah, M. A., Yakub, O. Z., Ogunlewe, O. O., Etus, P. C. et al. Antibiotic Resistance Patterns of *Escherichia coli* Isolated from Drinking Water Sources: Implications for Public Health and Surveillance Strategies. *International Journal of Advanced Biological and Biomedical Research*. 2026; 14(1): 127–145. doi: 10.48309/ijabbr.2026.2063804.1622
  9. Tadesse, B. T., Ashley, E. A., Ongarello, S., Havumaki, J., Wijegoonewardena, M., González, I. J. et al. Antimicrobial resistance in Africa: a systematic review. *BMC infectious diseases*. 2017; 17(1):616. <https://doi.org/10.1186/s12879-017-2713-1>
  10. Tacconelli, E., Carrara, E., Savoldi, A., Harbarth, S., Mendelson, M., Monnet, D. L. et al. Discovery, research, and development of new antibiotics: the WHO priority list of antibiotic-resistant bacteria and tuberculosis. *The Lancet. Infectious diseases*. 2018; 18(3):318–327. [https://doi.org/10.1016/S1473-3099\(17\)30753-3](https://doi.org/10.1016/S1473-3099(17)30753-3)
  11. Laxminarayan, R., Duse, A., Wattal, C., Zaidi, A. K., Wertheim, H. F., Sumpradit, N. et al. Antibiotic resistance—the need for global solutions. *The Lancet. Infectious diseases*. 2013; 13(12):1057–1098. [https://doi.org/10.1016/S1473-3099\(13\)70318-9](https://doi.org/10.1016/S1473-3099(13)70318-9)
  12. World Health Organization. Antimicrobial resistance. Fact sheet WHO. 2023. <https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance>
  13. World Health Organization. Global antibiotic resistance surveillance report 2025. WHO. 2025. <https://www.who.int/publications/i/item/9789240116337>
  14. Al-Khalaifah, H., Rahman, M. H., Al-Surrayai, T., Al-Dhumair, A. and Al-Hasan, M. A One-Health Perspective of Antimicrobial Resistance (AMR): Human, Animals and Environmental Health. *Life*. 2025; 15(10): 1598. <https://doi.org/10.3390/life15101598>
  15. Kapatsa, T., Lubanga, A. F., Bwanali, A. N., Harawa, G., Mudenda, S., Chipewa, P. C. et al. Behavioral and Socio-Economic Determinants of Antimicrobial Resistance in Sub-Saharan Africa: A Systematic Review. *Infection and drug resistance*. 2025; 18:855–873. <https://doi.org/10.2147/IDR.S503730>
  16. Ljungqvist, G., van Kessel, R., Mossialos, E., Saint, V., Schmidt, J., Mafi, A. et al. Mapping socioeconomic factors driving antimicrobial resistance in humans: An umbrella review. *One Health*. 2025; 20(1):100986. DOI:10.1016/j.onehlt.2025.100986
  17. Iskandar, K., Molinier, L., Hallit, S., Sartelli, M., Hardcastle, T. C., Haque, M. et al. Surveillance of antimicrobial resistance in low- and middle-income countries: a scattered picture. *Antimicrobial resistance and infection control*. 2021; 10(1): 63. <https://doi.org/10.1186/s13756-021-00931-w>
  18. Delpy, L., Astbury, C.C., Aenishaenslin, C., Arne Ruckert, A., Penney, T., Wiktorowicz, M. et al. Integrated surveillance systems for antibiotic resistance in a One Health context: a scoping review. *BMC Public Health*. 2024; 24, 1717. <https://doi.org/10.1186/s12889-024-19158-6>
  19. Ahmed, R. Emerging trends in antimicrobial resistance: A global review of surveillance, challenges, and strategies. *Premier Journal of Public Health*. 2025; 4: 100023. <https://doi.org/10.70389/PJPH.100023>
  20. LSHTM analysis. WHO's 2025 GLASS Report: Progress, patterns and persistent gaps. London School of Hygiene & Tropical Medicine. Antimicrobial resistance centre. 2025. <https://www.lshtm.ac.uk/research/centres/amr/news/473666/whos-2025-glass-report-progress-patterns-and-persistent-gaps>
  21. PLOS Global Public Health. New analysis reveals major global gaps in genomic surveillance of antimicrobial resistance. Pandemic Science Institute. 2025. <https://www.psi.ox.ac.uk/news-and-opinion/new-analysis-reveals-major-global-gaps-in-genomic-surveillance-of-antimicrobial-resistance-amr-2013-a-call-to-action>
  22. Siaba, S., Casal, B. and López-Martínez, I. The Economics of Antibiotic Resistance: A Systematic Review and Meta-analysis Based on Global Research. *Appl Health Econ Health Policy*. 2026; 24: 15–46. <https://doi.org/10.1007/s40258-025-01001-7>
  23. Warriar, A., Thanusubramanian, H., Routray, A. and Mane, A. Clinical and economic impact of antimicrobial resistance: Role of antimicrobial stewardship programs in Indian hospitals. *Journal of Academy of Hospital Administration*. 2023; 35(2): 60–70. [https://doi.org/10.4103/jaha.jaha\\_7\\_24](https://doi.org/10.4103/jaha.jaha_7_24)

24. Naylor, N. R., Hasso-Agopsowicz, M., Kim, C., Ma, Y., Frost, I., Abbas, K. et al. The global economic burden of antibiotic-resistant infections and the potential impact of bacterial vaccines: a modelling study. *BMJ Global Health*. 2025; 10(6): e016249. <https://doi.org/10.1136/bmjgh-2024-016249>
25. Aslam, B., Asghar, R., Muzammil, S., Shafique, M., Siddique, B., Khurshid, M. et al. AMR and Sustainable Development Goals: at a crossroads. *Global Health*. 2024; 20:73. <https://doi.org/10.1186/s12992-024-01046-8>
26. Anderson, M., Ljungqvist, G. and Saint, V. Socio-economic inequalities drive antimicrobial resistance risks: Here's how to curb it. *European Observatory on Health Systems and Policies/World Economic Forum*. 2024. <https://eurohealthobservatory.who.int/newsroom/news/item/11-05-2024-socio-economic-inequalities-drive-antimicrobial-resistance-risks.-here-s-how-to-curb-it>
27. Okonkwo, R. I., Ndukwe, H., Grant, G. and Khan, S. Antimicrobial stewardship in the community setting: a qualitative exploratory study. *Antimicrobial resistance and infection control*. 2025; 14(1):9. <https://doi.org/10.1186/s13756-025-01524-7>
28. James, R., Hardefeldt, L. Y., Ierano, C., Charani, E., Dowson, L., Elkins, S. and Thursky, K. Antimicrobial stewardship from a One Health perspective. *Nature reviews. Microbiology*. 2026; 24(2):146–162. <https://doi.org/10.1038/s41579-025-01233-3>
29. Willemsen, A., Reid, S. and Assefa, Y. A review of national action plans on antimicrobial resistance: strengths and weaknesses. *Antimicrobial resistance and infection control*. 2022; 11(1):90. <https://doi.org/10.1186/s13756-022-01130-x>
30. Gilham, E. L., Pearce-Smith, N., Carter, V. and Ashiru-Oredope, D. Assessment of global antimicrobial resistance campaigns conducted to improve public awareness and antimicrobial use behaviours: a rapid systematic review. *BMC public health*. 2024; 24(1):396. <https://doi.org/10.1186/s12889-024-17766-w>
31. Van Boeckel, T. P., Brower, C., Gilbert, M., Grenfell, B. T., Levin, S. A., Robinson, T. P. et al. Global trends in antimicrobial use in food animals. *Proceedings of the National Academy of Sciences of the United States of America*. 2015; 112(18): 5649–5654. <https://doi.org/10.1073/pnas.1503141112>
32. Theuretzbacher, U. Challenges and strategies for addressing antibacterial drug resistance in LMICs. *Nature reviews. Microbiology*. 2024; 22(10):591–592. <https://doi.org/10.1038/s41579-024-01080-8>

**Cite this article:** Moses Adondua Abah et.al. *A Review of the Global Burden of Antimicrobial Resistance: Trends, Challenges, and Future Directions* *Era Journal of Public Health and Community Medicine (EJPHCM)* 2026; 3(1): 32-42.

**Copyright:** © 2026. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.