The Research of Medical Science Review
ISSN: 3007-1208 & 3007-1216 Volume 3, Issue 10, 2025

THE IMPACT OF ANTIMICROBIAL RESISTANCE ON HUMAN HEALTH

Muhammad Muzammil Masood[1], Husnain Khalid[2], Maryam Ramzan[*3], Farheen Anwar[4]

[1,2,*3]*Department of Allied Health Professionals, Government College University, Faisalabad, Pakistan,*
[4]*Department of Zoology. University of Sargodha, Pakistan,*

[1]chm45761@gmail.com, [2]husnainkhalid1003@gmail.com, [*3]ramzanmaryam69@gmail.com,
[4]farheenanwar_87@yahoo.com

DOI: https://doi.org/10.5281/zenodo.17431166

Keywords
Antimicrobial resistance, Global health burden, One Health approach, Antibiotic Stewardship, Multidrug resistance, Economic impacts of AMR, Emerging pathogens

Article History
Received: 27 August 2025
Accepted: 09 October 2025
Published: 24 October 2025

Copyright @Author
Corresponding Author: *
Maryam Ramzan

Abstract

Antimicrobial resistance (AMR) is the ability of microorganisms to withstand the drugs that are designed to kill them, making infections harder to treat. It is one of the growing Global threats, affecting people by increasing illness, mortality and healthcare cost worldwide. AMR is a major Global Health crisis fueled by the misuse of antimicrobials in medicine, agriculture and environment. As resistant pathogens continue to emerge faster than the development of new drugs, AMR threatens the success of infection control strategies and modern medical treatments. This study explores the Global threat posed by AMR, highlighting how the ineffectiveness of antimicrobials against common pathogens jeopardize human health and the treatment of infectious diseases. Our findings demonstrate that antimicrobial resistance (AMR) stems from interconnected human, agriculture and environmental drivers leading to increased disease severity, treatment failures, healthcare strain and economic losses. The results challenge the traditional view that AMR is primarily driven by clinical antibiotics misuse, instead emphasizing its multi-dimensional origins. This review provides evidences that human behavioral factors, environmental reservoirs and agriculture antibiotic use are equally interact to drive resistance evolution. These insights extend prior knowledge emphasizing that AMR control demands cross-sectional collaboration with the One Health framework. Addressing AMR is not just a medical priority but also a corner stone of medical development and public health resilience.

INTRODUCTION

One of the most significant developments of modern science is the discovery of antibiotics. The impact of antibiotics has been instrumental in saving millions of lives worldwide(Marston et al., 2016). Antibiotic discovery is a remarkable chapter, with pioneers like Alexander Fleming and Selman Waksman setting the stage for life-saving treatments and motivating scientists to search for new antibiotics(Zakeri & Lu, 2013). Salvarsan was the first antimicrobial agent discovered in 1910 which was followed by the discovery of penicillin in 1928(Saga & Yamaguchi, 2009). Antibiotics have altered medicine, playing a role in life saving procedures and drastically reducing mortality rate in immunocompromised people(Lewis, 2017). Antimicrobials are the substances that fight microorganisms, including bacteria, fungi, parasites and viruses. All the antibiotics are antimicrobials but not all the antimicrobials are antibiotics(AGISAR, 2017). Antimicrobials are derived from natural or synthetic sources which includes antibiotics, antifungals, antiparasitic, and antivirals(Ali et al., 2018). However, antimicrobial resistance (AMR)

poses a significant threat to their progress(Marston et al., 2016). Antimicrobial resistance (AMR) is a major health challenge of 21st century(Prestinaci et al., 2015).The prospect of a future where antibiotics are ineffective against infections is a worrying scenario(Dadgostar, 2019). According to WHO, antimicrobial resistance occur when microorganisms like bacteria, viruses, fungi, parasites develop the capability to withstand treatments that were previously effective(Totaro et al., 2025). Antimicrobial resistance is fueled by the misuse and over use of antimicrobials, including taking antibiotics for viral infections, not completing treatment courses or self-medication, which accelerates the natural evolution of microbes(Zulfkar et al., 2025). The overuse of antimicrobials in medicine, agriculture and households stimulates the natural adaptation of infectious agents, leading to reduced effectiveness of previous treatments and increasing complexity of epidemic control(Morrison & Zembower, 2020). AMR is a major public health concern worldwide, with an estimated 5 million deaths from infections resistant to antibiotics(Ho et al., 2025). If current situation continues, then by 2050, antimicrobial resistance (AMR) could claim upto 10 million lives annually, surprising other major causes of death and resulting in a post-antibiotic era with devastating health consequences(Belay et al., 2025). This major challenge to global health is affecting countries across the developmental spectrum(Akber et al., 2025). WHO has recognized priority pathogens that demand urgent research and development (Harkin, 2022). There is a substantial impact on socio-economic factors with a prospective costs to the global economy estimated at US$100 trillion by 2050 (Harkin, 2022).

AMR has devastating impacts on immunocompromised populations(such as cancer patients, organ transplant recipients and people living with HIV/AIDS), neonates and elderly individuals, particularly in low and middle-income countries with resource-constrained settings(Holmes et al., 2025). According to a 2022 Lancet study, AMR caused 1.27 million deaths and 5 million associated deaths in 2019(Hussain et al., 2025). Its impacts are particularly high in regions with weak healthcare systems, such as Africa and Asia, where limited resources aggravate the problem. In sub-Saharan Africa, AMR is stimulated by socioeconomic factors, weak healthcare systems and inadequate regulation of pharmaceutical regulation, underscores the need for targeted interventions and is recognized one of the top 10 global health threats(Totaro et al., 2025). Antimicrobial resistance is a multifactorial problem that requires a One Health solution, considering the intricate connections between human, animal and environmental health (McEwen & Collignon, 2018). The widespread use of antibiotics in livestock and agriculture has accelerated the development of resistant organisms, which can be transmitted to humans through direct contact, food or water (Economou & Gousia, 2015). This review explores the critical intersection of AMR, public health and emerging pandemics, highlighting the importance for a One Health approach in developing sustainable strategies because antimicrobial resistance spreads across humans, animals and the environment making isolated interventions insufficient. By addressing these interconnected issues, we can protect both human and planetary health from growing threats of AMR.

Mechanisms of Antimicrobial Resistance:

Bacterial Resistance Mechanisms:

The ability of bacteria to develop resistance to antimicrobial agents makes the treatment of bacterial infections increasingly challenging (Tarin-Pello et al., 2022). In bacteria, resistance is basically determined by two genetic routes: spontaneous mutations and horizontal gene transfer(Galgano et al., 2025).

Mutation (Chromosomal Resistance): One of the fundamental routes through which bacteria acquire resistance is through Chromosomal mutations. These mutations arise randomly and are designated under antimicrobial pressure(Mohanty et al., 2021). Through these mechanisms bacteria can inactivate drugs, alter target sites, modify cell permeability and employ efflux pumps, ultimately reducing antibiotic efficacy(Zhang et al., 2024). Antimicrobial resistance can be broadly classified as mutational, intrinsic or transferrable. A well-known example is Rifampicin resistance in *Mycobacterium tuberculosis* through mutations in rpoB gene(Li et al., 2021).

Horizontal Gene Transfer (Acquired Resistance):
Horizontal gene transfer (HGT) plays a crucial role in the acquisition and dissemination of antimicrobial resistance (AMR) (Vaishampayan & Grohmann, 2021). It occurs through three main mechanisms: conjugation, transformation and transduction(Shen et al., 2022). **Conjugation:** The most important mechanism of antibiotic resistance via HGT is the transfer of plasmids and integrative elements through conjugation. It comprises the transfer of DNA from a donor bacterium to a recipient by direct contact. These are mobile elements and efficiently spread resistance(Shen et al., 2022). **Transformation:** The process in which bacterial cells actively take up free DNA from the environment and recombine it into their genome or maintain it as extra-chromosomal element is called natural transformation(Winter et al., 2021). **Transduction:** The process of transduction is facilitated by bacteriophages by packaging chromosomal DNA from host cells and delivering it to new bacterial hosts, disseminating resistance without cell to cell contact(Wachino, 2025). For example, Plasmid mediated Beta-Lactamase production in *Escherichia coli* confers resistance to beta-lactam antibiotics(Levison, 2002). In addition to these mechanisms, **Transposons** and **Integrons** (mobile genetic elements) further increase the spread of resistance genes within microbial populations (Kumavath et al., 2025).

Molecular Mechanisms of Antibiotic Resistance:
Bacteria employ several molecular mechanisms to resist antibiotics, including Enzymatic degradation, modification of drug target site, efflux pumps, reduced permeability and metabolic bypass pathways(Belay et al., 2024). In order to develop the effective strategies to combat AMR, it is crucial to understand these mechanisms(Darby et al., 2023).

Enzymatic degradation or modification:
The predominant strategy, affecting multiple classes of antibiotics such as Beta-Lactamase, aminoglycosides and macrolides involve enzymatic degradation or chemical modification of drugs. This process involves either complete hydrolysis of antibiotic molecule or its inactivation through chemical group binding(El-Khoury et al., 2022). For Example: Beta-Lactam ring of penicillin is hydrolyzed by Beta-lactamases, leading to drug inactivation (Costa et al., 2020).

Alteration of Drug Target:
Mutation or acquisition of alternative target proteins can reduce antibiotic binding and efficacy(Wang et al., 2025).For example: MRSA changes its penicillin-binding protein via mecA gene(Zhan & Zhu, 2018).

Efflux pumps:
Efflux pump enables bacteria to expel various antibiotics from bacterial cell and decrease their intracellular concentrations below therapeutic levels (Huang et al., 2022). Many efflux systems in bacteria are multidrug pumps, contributing to the broad-spectrum resistance. This is an innate feature of bacteria, potentially used to remove harmful natural substances(Ghoshal et al., 2023). For Example: Tetracycline resistance is often mediated by efflux pump (Li et al., 2023).

Reduced Permeability:
It involves alterations in the outer cell membrane porins that limit the antibiotic uptake, particularly in gram-negative bacteria(Lepe & Martínez-Martínez, 2022). For example *Pseudomonas aeruginosa* reduces the entry of carbapenems and other hydrophilic antibiotics (Aurilio et al., 2022).

Bypass Pathways:
Some bacteria develop alternative metabolic pathways that bypass the inhibited step, thereby contribute to evade antibiotic action (Peng et al., 2023). For Example: Trimethoprim resistance arises when bacteria acquire alternative dehydrofolate reductase enzymes, causing folate synthesis inhibition(Flensburg & Sköld, 1987).

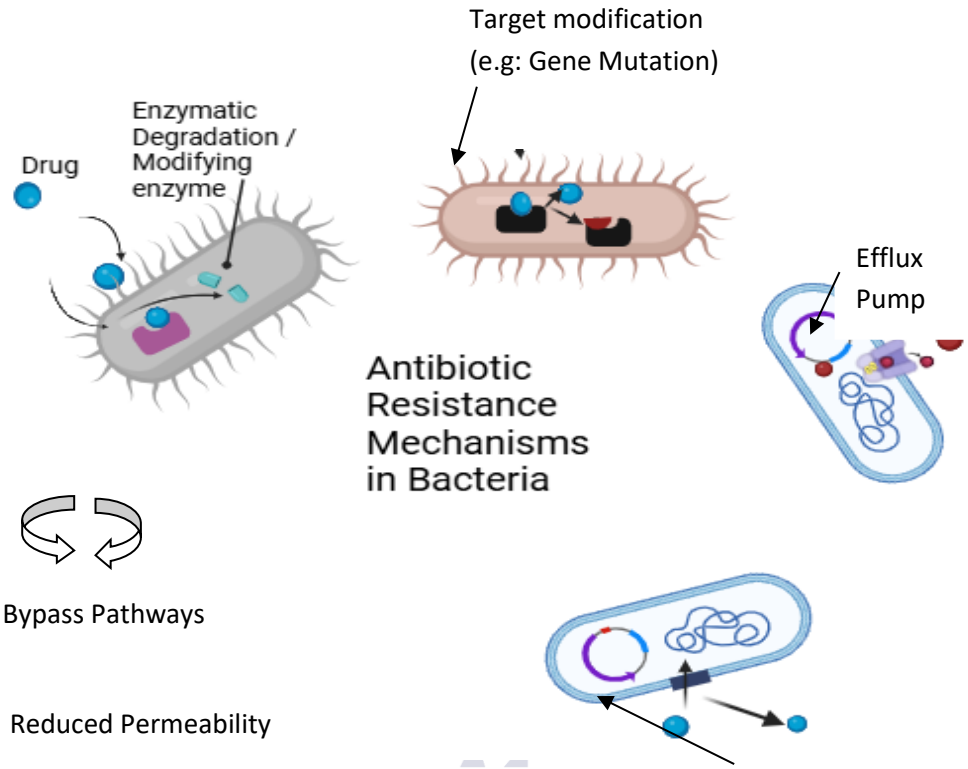


Fig1: Schematic representation of Molecular Mechanisms of antibiotic resistance in bacteria

Fungal Mechanisms:

Due of the increasing use of antifungal agents and limited number of available drug classes, fungal resistance has emerged as a major clinical concern(Cowen et al., 2015). Fungi can also develop similar resistance mechanisms as bacteria, involving biofilm formation, target modification and enhanced efflux pump activity(AlMatar et al., 2021). Understanding these mechanisms is crucial for preserving the effectiveness of antifungal drugs and to combat the growing threat of resistance(Lee et al., 2023).

Target Modification: Structural alterations in fungal target molecule can reduce antifungal binding and efficacy(Ivanov et al., 2022). For example, resistance to azoles due to the mutations in ERG11 gene, which encodes Lanosterol 14-alpha demethylase(Singh et al., 2023). These mutations alter the enzyme structure, decreasing azole affinity and inhibiting the synthesis of ergosterol, which is essential for fungal cell membrane formation(Ahmed et al., 2021).

Biofilm Formation: The fungal cells embedded in an extracellular matrix (ECM) form Biofilms which adhere to the surfaces and create suitable microenvironments for the survival, thus protecting the cells from environmental stresses (Ansari et al., 2021). During biofilm maturation, a key resistance mechanism is involved in the development of hypoxic microenvironment, especially in Aspergillus fumigatus, where Oxygen levels determine antifungal resistance and involve in the treatment failure(Stevanovic et al., 2022). As a result, biofilm-mediated fungal infections are often difficult to treat, demanding higher drug doses and prolonged treatment(Roudbary et al., 2022).

Efflux Pump activity: The mechanism of reducing intracellular drug concentrations to sub-lethal levels by actively extruding antifungals from fungal cells is mediated by efflux pump activity, that contribute the multi-drug resistance development (Sardana et al., 2023). The key genes in this activity include MDRI, CDRI and CDR2. These genes are overexpressed in clinical isolates, especially in azole resistance(Paiva Macedo & Dias, 2024).

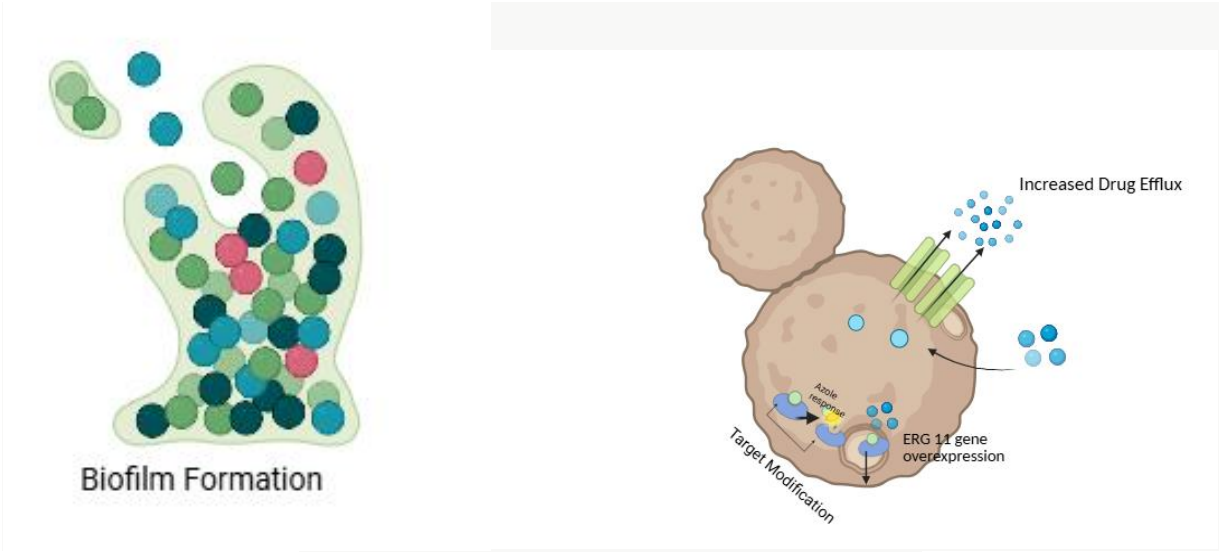


Fig2: Fungal mechanisms of antimicrobial resistance

Viral Mechanisms:

Antiviral drug resistance signifies a major obstacle in controlling viral infections, leading to treatment failure and limiting therapeutic options. High mutation rates and rapid replication cycles in viruses enables the emergence of viral escape mutants under selective drug pressure, thereby reducing drug efficacy(Kausar et al., 2021) (Domingo et al., 2021). The major challenge for the management and treatment of viral infections is the emergence of drug-resistant viral strains(Smyk et al., 2022). Viruses can quickly adapt to selective pressure imposed by antiviral drugs, contribute to the development of resistance(Smyk et al., 2022). Resistance is particularly common in RNA viruses such as HIV and influenza virus has high mutation rates and are prone to develop drug-resistance. For example, HIV resistance often arises through protease genes and reverse transcriptase, compromising antiviral therapy. DNA viruses can also develop resistance through mutations in polymerase gene and most recently, SARS-CoV-2 has reduced susceptibility to monoclonal antibodies due to the mutations in spike proteins. The uncontrolled emergence of novel drug-resistant viral strains requires surveillance and the development of new antiviral agents(Smyk et al., 2022).

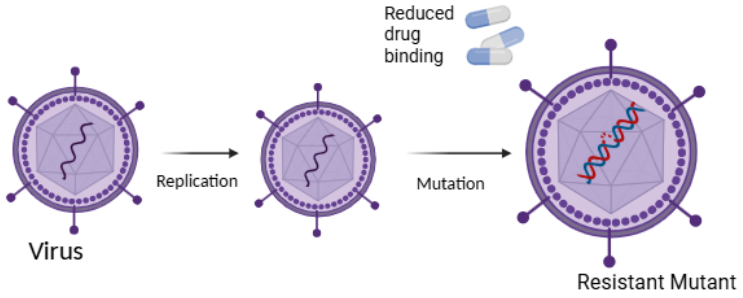


Fig3: Mechanism of Viral antimicrobial resistance

Table1: Impact of Antimicrobial Resistance on major human infections:

Infection Type	Common Resistant Pathogens	Resistance Mechanisms	Clinical Impacts	Human Health Burden
Respiratory tract Infections	*Mycobacterium tuberculosis*, *Klebsiella Pneumoniae*, MRSA	Altered penicillin binding proteins(MRSA), mutation in ribosomal genes, Beta lactamase production, Drug Efflux	High mortality, Prolonged therapy, Treatment failure	Globally, it is the leading cause of deaths (approximately 1.5M from TB annually) (Ingelbeen, 2023)
Urinary tract infections	*E.coli*, Carbapenem-resistant *Enterobacteriaceae* (CRE), *Klebsiella*	Extended spectrum beta-lactamases (ESBLs),enzymatic inactivation, porin loss	Hospitalization cost, High recurrence, pyelonephritis, sepsis risk	150M cases annually worldwide, High morbidity in women, catheterized patients(Mohamed et al., 2022)
Bloodstream Infections	MRSA, *Enterococcus faecium*, CRE, VRE	Altered penicillin binding proteins(MRSA), Biofilm formation	Multi-organ failure, septic shock, High ICU mortality	Morbidity up to 30-40% in resistant septicemia (Di Franco et al., 2021)
Skin and Soft tissue Infections	**MRSA, MDR, *Pseudomonas aeruginosa***	**Efflux pump, Biofilm formation**	**Delayed wound healing, prolonged hospital stays, chronic wound infections, amputation risks**	**High in trauma or surgical patients (Sartelli et al., 2022)**
Opportunistic Infections	*Candida auris*, *Aspergillus* species, MDR, Gram-Negative rods	Biofilm formation in *Candida auris*, target site mutation, efflux pump	High mortality in immunocompromised	Emerging global fungal threats, rising hospital mortality

Impact on vulnerable population:

Neonates and Children:

Neonates and Children represent one of the most vulnerable populations to AMR because of the frequent exposure to antibiotics and limited treatment options(Bamford et al., 2024). They are at a comparatively higher risk of bacterial infections due to their delicate physiological system, higher

exposure to bacteria and lack of sufficient immunity (Mustafa et al., 2022). In the Asia-pacific region, where about 600 million children live, AMR associated infections contribute to the huge burden of mortality & morbidity(Bamford et al., 2024). Neonatal sepsis causes global mortality and morbidity, particularly in low resourced areas where 99% of neonatal deaths occur (Sturrock et al., 2023). Resistant infections in this population can lead to serious complications such as meningitis, sepsis, necrotizing enterocolitis, which can drastically increase mortality rates (Cormontagne et al., 2021). A study reported that 23% of antimicrobial resistance genes were detected in premature infants who had no direct or intrapartum exposure of antibiotics (Ojeda et al., 2024). Maternal antibiotic use during gestation and delivery and prolonged rupture of membranes have been linked to alterations in premature infant resistome and microbiome (Ojeda et al., 2024). Treatment options are limited and the need for specialized care increase the burden on healthcare systems. The frequent need of intensive care further exposes them to resistant organisms (Sulis, Sayood, Katukoori, et al., 2022). Strict infection control measures and the use of last-option antibiotics are expensive and are not always effective. In order to overcome the challenge of AMR in neonates and infants, advanced diagnostic tools and the development of novel antimicrobial agents is essential (Skender et al., 2025).

Elderly Population:

Elderly population faces increased susceptibility to antimicrobial resistance, with this vulnerable group serving as a primary reservoirs of multidrug-resistant organisms. In hospitals, older patients (above 65 years) have higher rates of infection with multidrug-resistant organisms including MRSA, VRE and multidrug-resistant Gram-negative bacteria(Denkinger et al., 2013). The factors that increase their vulnerability to multi-drug resistant infections are aging-related changes including polypharmacy, weakened immune system and frequent hospitalization (Ahamed et al., 2024). Elderly population discriminating vulnerability to antimicrobial resistance as a result of frailty, immunosenescence, multiple comorbidities, and frequent exposure to hospitals(Wilson & Seaton, 2024). It is proved from global data that while AMR has decreased in young children over recent decades but it has increased by 80% among adults aged 70 years and older (Naghavi et al., 2024). The changes in immune system such as reduced T cell function and impaired pathogen recognition increase the risk of infection. Comorbidities like, heart disease, chronic lung disease and diabetes compromise the immune system and increase the risk of AMR infections(DeMaio et al., 2022). These infections can lead to the increased mortality, reduced quality of life and long-term hospital stays. The use of more toxic and expensive antimicrobial agents to treat resistant infections in elderly population can have significant side effects (Soraci et al., 2023). The long-term hospital stays associated with AMR infections increase the risk of healthcare associated infections and further subsidize to the burden on healthcare systems (Abban et al., 2023). The usage of multiple medications can disturb the balance of gut microbiome, making populations more susceptible to infections. So AMR is a significant challenge in elderly patients but culture and sensitivity tests can reduce unnecessary antibiotic use, rapid diagnosis and appropriate therapy are crucial (Indrayuni et al., 2022).

Immunocompromised Patients:

Immunocompromised patients are particularly susceptible to infectious complications due to their reduced ability to fight infections and frequent antibiotic exposure(Bassetti et al., 2025). Treatments such as immunosuppressive medications, chemotherapy and organ transplantation further aggravate this susceptibility, which result in alteration in the duration, presentation, frequency and severity of infections, particularly opportunistic infections. (Sadeghi et al., 2025). Cancer treatments are negatively affected by AMR and contributing to increased cancer related mortality(Lawal et al., 2024). Bacterial pneumonia and sepsis are most common infections in hospitalized cancer patients with the reported mortality of 8.5% in cancer patients due to severe sepsis (Ture et al., 2025). The cancer patients has prevalence rates of resistant pathogens ranges from 1.5% for carbapenem-resistant pathogens to 53% for MRSA(Sadeghi et al., 2025). Similarly, children with compromised immune system

especially those undergoing stem cell or organ transplantation or with hematological malignancies are highly susceptible due to neutropenia, prolonged antibiotic exposure and repeated hospital contact(Zajac-Spychala et al., 2022). Strict control measures and the use of last-option antibiotics are necessary but can be costly and ineffective (Muteeb et al., 2023). In order to reduce the risk of infection in this population, strategies to improve immune system such as vaccination and immunomodulatory therapies can be used.

Pregnant Women:

Antimicrobial resistance poses a serious threat to pregnant women, considerably compromising treatment options for common infections like urinary tract infections, thus increasing maternal and neonatal mortality and morbidity risks. UTIs are the most common bacterial infections in pregnancy. There is a lack of new antibiotics for UTI(Patnool et al., 2022). A study found that 85% antimicrobial resistance burden in pregnant women is because of UTI(Al Kadri et al., 2024). Antibiotics are most commonly used medications to treat UTIs globally and thus the sustainable and excessive use of antibiotics has been a major cause of antibiotic resistance(K. I. Yeta et al., 2021). A study in Zambia showed 53% of pregnant women with UTIs showed antimicrobial resistance(Kekelwa Inyambo Yeta et al., 2021). Similarly, Ethiopian data from 5894 urine samples revealed multidrug resistance rates of 83% for *E.coli*, 89% for *Staphylococcus aureus* and 78% for *Klebsiella species*(Chelkeba et al., 2022). The burden extends beyond UTIs. A retrospective analysis of 274 samples from 246 pregnant women found that 9.63% of Group B Streptococci were resistant to penicillin, 23.36% were multi-drug resistant, MRSA and MDR S. aureus were detected in 50% and 54.54% of S. aureus positive samples respectively(Vlad et al., 2025). The consequences of multi drug resistance are increased mortality and morbidity rates. With over 700,000 deaths annually, a figure projected to rise up to 10million by 2050 (James). There is a need to develop integrated surveillance systems that goal for regular and early screening of pregnant women for UTI as well as determination of antibiotic susceptibility patterns (Ngong et al., 2021). This is very important to prevent complications that may cause maternal and fetal outcomes.

Low and Middle Income Countries:

Antimicrobial resistance disproportionately affects low and middle-income countries, where the economic and health consequences are far exceed than those seen in high-income nations (Sulis, Sayood, & Gandra, 2022). This burden is exacerbated by the combination of high rates of communicable diseases, poor surveillance systems, weak healthcare infrastructure and widespread use of antibiotics(Sulis, Sayood, & Gandra, 2022). According to WHO, all countries are affected by AMR and at all income levels but its consequences are exacerbated by poverty and inequality, and low and middle-income countries are most affected (Sulis, Sayood, & Gandra, 2022). In Sub-Saharan Africa, the mortality rates associated with AMR are highest globally, reflecting weak infection control systems and delayed access to effective treatment (Kariuki et al., 2022). For example, blood stream infections by E.coli resistant to 3rd generation cephalosporins are estimated to cause more than 100,000 deaths in Africa and Asia (Aiken et al., 2023). Progress is being made in low and middle-income countries in implementing surveillance measures but the meaningful measures must address the structural issues that generate and promote AMR Progress is being made in low and middle-income countries in implementing surveillance measures but the meaningful measures must address the structural issues that generate and promote AMR (Sulis, Sayood, & Gandra, 2022). Because low and middle income countries have limited healthcare access and socioeconomic differences. Strategies to combat these problems including improving healthcare settings and promoting responsible antimicrobial use(Rony et al., 2023).

Table2: Trends of AMR in vulnerable population groups

Vulnerable Groups	Main risk factors	Common resistant pathogens	Clinical impacts
Neonates and Children	Maternal antibiotic use, intensive care exposure, immature immunity	Klebsiella, E.coli, GBS, MRSA	Meningitis, sepsis, increased mortality , NEC
Elderly population	Frequent hospitalization, polypharmacy, Immunosenescence, multimorbidity, frailty	Pseudomonas, MRSA, VRE, CRE, MDR	Longer hospital stays, increased hospital acquired infections, higher mortality
Immunocompromised patients	Cancer, chemotherapy, organ transplantation, stem cell transplant, HIV/ AIDS	Gram negatives, Candida auris, MRSA, MDR	Pneumonia, sepsis, poor treatment outcomes, increased mortality
Pregnant women	Limited safe antibiotic choices, frequent UTIs, weak surveillance	Klebsiella, MRSA, GBS, E.coli	Neonatal sepsis, preterm birth, maternal mortality
Low and middle-income countries	Counterfeit drugs, weak healthcare systems, excessive antibiotic use, poor sanitation	MDR Gram- negatives, MRSA, VRE	Limited treatment options, high AMR mortality, economic burden

Global Burden of AMR:

Mortality and Morbidity:

Longer hospital stays due to AMR increases healthcare cost, the use of last-option antibiotics and the need for more expensive treatments (Muteeb et al., 2023). Globally, AMR causes substantial mortality and morbidity, with recent estimates hundreds of thousands of annual deaths and significant increase in hospital stays, illness burden and healthcare costs (Murray et al., 2022). The mortality evidence is geographically limited but concrete. According to a study, current data shows approximately 700,000 deaths per year due to AMR(Capozzi et al., 2019). AMR directly caused 1.14 million deaths and in 2021, 4.71 million deaths globally, a significant increase from 1.27 million deaths in 2019 directly, thus a major global public health threat. The recent data showing up to 4.95 million deaths associated with AMR in 2019, out of which 1.27 million directly attributable deaths. The burden is evenly distributed to Africa having mortality rate at 27.3 deaths per 100,000 people(Oliveira et al., 2024). In Australia, 1,031 deaths related to AMR in 2020 from just five hospital associated infections, being the first national estimate(Wozniak et al., 2022). Although AMR is a global issue but there is a lack of reliable data on its geographical distribution and trends; integration of AMR data into the Global Burden of Diseases Study goals to improve assessments and policy-making(Hay et al., 2018). However, there are some data quality limitations, especially in low and middle-income countries where there is inadequate capacity for healthcare surveillance(Dunachie et al., 2020).

Economic Burden:

Antimicrobial resistance (AMR) has potentially far-reaching economic consequences, staining both healthcare systems and national economies (Aslam et al., 2024). The economic burden of AMR is considerable. Currently, the economic burden of AMR is estimated at $730 billion annually with projections reaching $100 trillion by 20500, if trends continue(Naylor et al., 2018). The economic burden of AMR is substantial at the national level, with recent studies focusing on direct healthcare costs: 30 reports are available covering 67 countries but still further data and guidance is needed for decision-making(Gheorghe, 2024). According to regional estimates, Europe's 9 billion euros annually and the

$20 billion in direct cost of healthcare system plus $35 billion in productivity losses(Haruna et al., 2024). In country-specific studies, Thailand's $2.3 billion annual cost of treatment(Phodha et al., 2019). In Pakistan, $33.97 additional cost per AMR cases(Safdar et al., 2025). However, the main focus is on direct healthcare costs, with fewer estimations of indirect economic impacts(Gheorghe, 2024).

Factors contributing to AMR:

Human factors

Human factors are significant carters of antimicrobial resistance through multiple pathways including healthcare practices, misuse of antibiotics, conflict and mobility(Desai et al., 2022). Inappropriate prescriptions such as antibiotics prescription for viral infections, contribute to unnecessary exposure to antibiotics (Obolski et al., 2021). Without prescription, self- medication with antibiotics is also a trigger as patients may fail to use the drug correctly or complete the full course of treatment. Robust quantitative evidence comes from a large-scale Chinese study analyzing 20,762,383 bacterial isolates over 8 years across 31 provinces, which concluded that human antibiotic usage was associated with a 1.8% increase in exacerbate antimicrobial resistance per unit increase, while prolonged hospital stays showed the strongest association at 8.0% increase(Zhou et al., 2025). Additional studies identify other key human factors: inappropriate prescribing and sales(Marston et al., 2016), international travel and displacements (Pallett et al., 2023), armed conflicts that disrupts healthcare systems and transmission via human-human interaction in healthcare settings. However, most of the studies lack quantitative effect sizes and are limited geographically, but the global applicability of these human factors is strongly suggested by qualitative evidences.

Antimicrobial use in Agriculture

The widespread use of antimicrobials in agriculture significantly contribute to AMR that increases mortality and cause severe infections (Tang et al., 2023). Agriculture sector accounts for the largest share of global antimicrobial consumption, at sub therapeutic level, creating ideal conditions for resistance selection. A systemic GRADE framework review concluded that there is a compelling scientific evidence across the full casual pathway from the use of antimicrobial on farms to a public health burden caused by infections with resistant pathogens(Hoelzer et al., 2017). Resistant foodborne pathogens such as *Salmonella* and *Campylobacter* are of great concern (Grudlewska-Buda et al., 2023). For example, resistant to third generation cephalosporins and fluoroquinolones which are clinical important drugs for these infections has been repeatedly documented. Such resistance lead to prolonged duration of illness, increased rates of bacteremia, excess cases of illness, hospitalization and death(Tollefson & Karp, 2004). However, the exact quantification of the human health burden directly attributable to the use of antimicrobial drug in animal agriculture compared to the other drivers remains challenging.

Environmental contamination

Environmental contamination represents a major transmission pathway and reservoir for AMR (Hazards et al., 2021). Pharmaceutical effluents and wastewater treatment plants are recognized as primary contamination sources. The evidence base is strong but geographically diverse. Multiple systemic reviews published between 2021-2025 consistently highlight environmental contamination as a key driver of AMR (Ahmad et al., 2021). A review analyzing 33 studies from six continents detected AMR strains in all aquatic environments studied, with high levels of resistant to beta-lactamases and tetracyclines (Cheung et al., 2025). Pharmaceutical effluents are recognized as a critical hotspot, often containing high concentrations of resistance genes and antibiotics (Kotwani et al., 2021). In France, wastewater treatment plants were recognized as the major sources of contamination, with fluoroquinolones and trimethoprim containing high- to medium risk for resistance selection (Haenni et al., 2022). Despite the strength of evidence, quantitative effect sizes and standard metrics are limited introduces methodological heterogeneity, complicating cross-regional studies (Haenni et al., 2022).

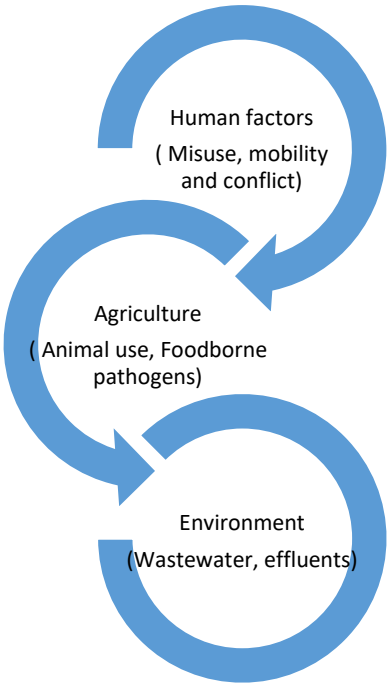


Fig4: Antimicrobial resistance Drivers

Strategies to combat AMR:

Antimicrobial Stewardship Programs

One of the most effective interventions that can significantly reduce Antimicrobial resistance and improve antibiotic prescription practices are Antimicrobial Stewardship programs (ASPs). Evidence across multiple settings support their effectiveness (Ya et al., 2023). According to a 14 year controlled study, it was concluded that ASPs reduced hospital acquired antibiotic-resistant organisms by 9% amnd MDR organisms by 13%. Similarly, a meta-analysis of 14 studies showed that ASPs reduced antimicrobial prescription rates with particular strong effects for rationalize interventions and improve guidline adherence(Dirjayanto et al., 2025). A study on 1,396 patients have significant improvements in bacterial culture rates from 47.3% to 77.65 over four quarters, representing better-targeted therapy. Antimicrobial Stewardship programs accomplish these outcomes through multidisciplinary approaches including pre-authorization systems, prospective audits, formulary management, and educational outreach(Rajesh et al., 2021). Other additional studies confirm ASPs reduce inappropriate use of use of antibiotics, healthcare cost and development of resistance through evidence-based interventions(Yadav et al., 2022). However, there are major challenges like implementation in low-resourced settings, lack of diagnostic tools, financial constraints and healthcare provider resistance. By integrating ASPs in One health framework may enhance their reach, linking human health care with animal and environmental stewardship to address resistance across different sectors (Roy et al., 2025).

Infection Prevention and Control:

Infection prevention and control measures are necessary to reduce the incidence of infections and the need for antimicrobial agents, thus preventing the spread of resistant organisms in healthcare settings and community(Tomczyk et al., 2021). These measures include isolation precautions, environmental cleaning, hand hygiene and vaccination, preventing the transmission of resistant pathogens from person to person and from environment to patients(Cegielski et al., 2021). According to a comprehensive modelling analysis, it was found that improved IPC programs in low-resourced countries healthcare settings could prevent

337,000 AMR- associated deaths annually(95% CI 250,200- 465,200), expressing 7.8% of all AMR linked mortality(Lewnard et al., 2024). Access to clean water and improved sanitation can also reduce the risk of infection, particularly in low- resourced areas. Universal access to water, sanitation and hygiene practices could prevent 247,800 AMR deaths and vaccination in children could prevent 181,500 AMR deaths(Lewnard et al., 2024). The study suggests that decreasing AMR burden by 10% by 2030 is attainable with previous interventions(Lewnard et al., 2024).

Research and Development of new Therapies:

The development of new antimicrobials provide new treatment options for resistant infections and preserving the effectiveness of antimicrobial therapy. Recent studies suggesting alternatives including bacteriophages, antimicrobial peptides, monoclonal antibodies, CRISPR technology and nanoparticles (Kuchay, 2024). Applications of nanotechnology using mesoporous materials promise as antimicrobial agents (Gomez et al., 2024). New antimicrobial agents are currently limited due to various factors, including the low return on investment, high cost of drug development, and the hurdles to bring new antimicrobial agents to market (Beyer et al., 2020). So research should focus on drugs effective against a broad range of resistant organisms, mechanism of action and novel targets can help to overcome the existing resistant mechanisms and prevent the emergence of new mechanisms. Public- private partnerships are required to encourage pharmaceutical companies and other organizations to invest in research and development (Sharma et al., 2025). These incentives can help to share the cost and risk of drug development and measures such as market exclusivity and tax credits can help to increase the return on investment for antimicrobial drug development. The Action Fund for AMR shows an investment with nearly $1 billion committed to bring 2-4 new antibiotics to market by 2030 (Beyer et al., 2020).

Surveillance and Monitoring:

Global surveillance networks provide the data on antimicrobial use and resistance patterns worldwide, thus tracking the emergence and spread of AMR. These networks collect data from hospitals, laboratories, and public health agencies (Coque et al., 2023). The data are used to identify emerging resistance threats, monitor AMR trends and inform public health interventions. The WHO plays an important role in organizing Global surveillance programs, providing technical assistance to countries and establishing standards for data collection and sharing. The key initiative for Global AMR surveillance efforts is the Global AMR & Use surveillance system (GLASS) (Kumar et al., 2020). GLASS targets to standardize data collection and reporting improve quality of data and provide a Global picture of AMR trends. Canada's AMR system shows integrated One Health approaches (Rudnick et al., 2022). However, analysis of sic European countries showed substantial heterogeneity in data sources, evaluation criteria and laboratory methods, making comparisons challenging (Mesa Varona et al., 2020). These measures are needed to improve surveillance, certifying that data are analogous across countries and regions.

Public awareness and Education:

Education campaigns and public awareness can promote safe antimicrobial use and hygiene practices, allowing individuals to take action to prevent the spread of AMR (Gilham et al., 2024). These campaigns can target both public and healthcare professionals, providing awareness on safe use of antimicrobials and infection prevention practices. A review covering 92 studies WHO African member found " low knowledge of AMR coupled with excessive misuse of antimicrobial medicines by different target populations" (Fuller et al., 2023). Effective public awareness can help to change the behaviors and reduce the spread of AMR (Fletcher-Miles et al., 2020). The WHO has synchronized awareness campaigns through public engagement remain sporadic (Rajkhowa & Thursky, 2020). Healthcare professional should be properly educated on the appropriate use of antimicrobials and the importance of antimicrobial stewardship programs (Kpokiri et al., 2021). Education of infection prevention and importance of vaccination is also important, reducing the need of antimicrobial agents and incidences of infection (Jansen et al., 2018).

One Health Approach to AMR:

As the problem of Antimicrobial resistance (AMR) is not only confined to hospitals and laboratories but also extends across humans, animals and the environment, so the concept on One Health approach has become central(Ponzo et al., 2024). The misuse of antibiotics in human medicine through self-medication, over prescription or poor infection prevention practices create selective pressure that allows resistant pathogens to grow (Rather et al., 2017). However, humans are not only source of resistance. Antimicrobials are often used in Livestock and aquaculture not only for treating infections but also for growth promotion and routine disease prevention (Ibrahim et al., 2020). This practice nurtures resistant pathogens in animals such as ESBL- producing *E.coli* and colistin-resitant *Klebsiella pneumonia*, which can transmit to humans through direct contact, food chain or zoonotic transmission (Apostolakos & Piccirillo, 2018). The environment is also an important part of this cycle. Hospital sewage, pharmaceutical waste, and agriculture runoff contaminate natural resources such as water, soil and crops with antibiotics and resistant organisms (Bansal, 2019). There can be a horizontal gene transfer to human pathogens via environmental bacteria that act as a reservoir of resistance genes (Juhas, 2015). Climate change, inadequate sanitation and floods can amplify this spread. As these domains are unified, solutions must be equally integrated. The One Health Approach demands for surveillance systems that can track resistance patterns in humans, animals, and ecosystems simultaneously, such as GLASS program of WHO (Singh et al., 2024). It also highlights the antimicrobial stewardship programs across medicine, veterinary practice and agriculture, with strict measures that control non-therapeutic use of antibiotics in food production (Khurana, 2019). Research into alternatives, including bacteriophage therapy, probiotics, rapid diagnostics, and vaccines, provide promising pathways to reduce dependence on conventional antibiotics (Helmy et al., 2023). Public awareness campaigns targeting farmers, communities and clinicians are equally important to ensure the responsible use of antimicrobials (MacPherson et al., 2022). In conclusions, One Health approach identifies that no single sector can combat AMR alone because resistant organisms can move freely between humans, animals and the environment but the interventions are likely to be succeeded. By integrating medical, agriculture, veterinary and environmental efforts, we can reduce the spread of resistance and protect both human and planetary health (Horvat & Kovačević, 2025).

Declaration

Authors' Contribution: All authors equally contributed to the study and approved the final manuscript.

Conflict of Interest: No conflict of interest.

Funding: No funding received by the authors.

REFERENCES:

Abban, M. K., Ayerakwa, E. A., Mosi, L., & Isawumi, A. (2023). The burden of hospital acquired infections and antimicrobial resistance. *Heliyon*, *9*(10).

AGISAR, W. (2017). Critically Important Antimicrobials for Human Medicine-5th Revision 2017. *Geneva, Switzerland*.

Ahamed, S. F., Muneer, H., Joekim, J. F., Parveen, N., & Vijay, K. (2024). The Intersection Of Aging And Antibiotic Resistance: Implications For Treatment And Healthcare Policy.

Ahmad, I., Malak, H. A., & Abulreesh, H. H. (2021). Environmental antimicrobial resistance and its drivers: a potential threat to public health. *Journal of global antimicrobial resistance*, *27*, 101-111.

Ahmed, M. Z., Rao, T., Saeed, A., Mutahir, Z., Hameed, S., Inayat, S., Shahzad, H., Ullah, N., Abaid-Ullah, M., & Ibrahim, M. (2021). Antifungal drugs: mechanism of action and resistance. In *Biochemistry of Drug Resistance* (pp. 143-165). Springer.

Aiken, A. M., Rehman, A. M., de Kraker, M. E., Madrid, L., Kebede, M., Labi, A.-K., Obeng-Nkrumah, N., Nyamwaya, B., Kagucia, E., & Cocker, D. (2023). Mortality associated with third-generation cephalosporin resistance in Enterobacterales bloodstream infections at eight sub-Saharan African hospitals (MBIRA): a prospective cohort study. *The Lancet Infectious Diseases*, *23*(11), 1280-1290.

Akber, S. S., Rao, F., Sidique, F., Hassan, H. A., & Rao, A. (2025). Antibiotic Resistant Infections. In *Antibiotics and Reproductive Health* (pp. 117-166). Bentham Science Publishers.

Al Kadri, H. M., El-Metwally, A. A., Al Sudairy, A. A., Al-Dahash, R. A., Al Khateeb, B. F., & Al Johani, S. M. (2024). Antimicrobial resistance among pregnant women with urinary tract infections is on rise: Findings from meta-analysis of observational studies. *Journal of Infection and Public Health*, *17*(7), 102467.

Ali, S. M., Siddiqui, R., & Khan, N. A. (2018). Antimicrobial discovery from natural and unusual sources. *Journal of Pharmacy and Pharmacology*, *70*(10), 1287-1300.

AlMatar, M., Albarri, O., Makky, E. A., & Köksal, F. (2021). Efflux pump inhibitors: new updates. *Pharmacological Reports*, *73*(1), 1-16.

Ansari, A., Kumar, D., Kumar, N., & Saumitro, M. (2021). BIOFILM AND RELATED ANTIMICROBIAL RESISTANCE. *Webology*, *18*(2).

Apostolakos, I., & Piccirillo, A. (2018). A review on the current situation and challenges of colistin resistance in poultry production. *Avian Pathology*, *47*(6), 546-558.

Aslam, B., Asghar, R., Muzammil, S., Shafique, M., Siddique, A. B., Khurshid, M., Ijaz, M., Rasool, M. H., Chaudhry, T. H., & Aamir, A. (2024). AMR and Sustainable Development Goals: at a crossroads. *Globalization and Health*, *20*(1), 73.

Aurilio, C., Sansone, P., Barbarisi, M., Pota, V., Giaccari, L. G., Coppolino, F., Barbarisi, A., Passavanti, M. B., & Pace, M. C. (2022). Mechanisms of action of carbapenem resistance. *Antibiotics*, *11*(3), 421.

Bamford, A., Masini, T., Williams, P., Sharland, M., Gigante, V., Dixit, D., Sati, H., Huttner, B., Nisar, Y. B., & Cappello, B. (2024). Tackling the threat of antimicrobial resistance in neonates and children: outcomes from the first WHO-convened Paediatric Drug Optimisation exercise for antibiotics. *The Lancet Child & Adolescent Health*, *8*(6), 456-466.

Bansal, O. (2019). Antibiotics in hospital effluents and their impact on the antibiotics resistant bacteria and remediation of the antibiotics: a review. *Network Pharmacology*, *4*(3-4), 6-30.

Bassetti, M., Cardone, A., Cardoso, F., Carter, V., Cornely, O. A., Falcone, M., Gallego, D., Giannella, M., Grossi, P. A., & Pagano, L. (2025). Can We Lower the Burden of Antimicrobial Resistance (AMR) in Heavily Immunocompromised Patients? A Narrative Review and Call to Action. *Infectious Diseases and Therapy*, 1-24.

Belay, W. Y., Getachew, M., Tegegne, B. A., Teffera, Z. H., Dagne, A., Zeleke, T. K., Abebe, R. B., Gedif, A. A., Fenta, A., & Yirdaw, G. (2024). Mechanism of antibacterial resistance, strategies and next-generation antimicrobials to contain antimicrobial resistance: a review. *Frontiers in Pharmacology*, *15*, 1444781.

Belay, W. Y., Getachew, M., Tegegne, B. A., Teffera, Z. H., Dagne, A., Zeleke, T. K., Wondm, S. A., Abebe, R. B., Gedif, A. A., & Fenta, A. (2025). Antimicrobial resistance with a focus on antibacterial, antifungal, antimalarial, and antiviral drugs resistance, its threat, global priority pathogens, prevention, and control strategies: a review. *Therapeutic Advances in Infectious Disease*, *12*, 20499361251340144.

Beyer, P., Cueni, T. B., Knox, J., & Riedl, F. (2020). A research and development fund for new treatments for bacterial infections. *Bulletin of the World Health Organization*, *98*(12), 822.

Capozzi, C., Maurici, M., & Panà, A. (2019). Antimicrobial resistance: it is a global crisis," a slow tsunami". *Igiene e sanita pubblica*, *75*(6), 429-450.

Cegielski, J. P., Tudor, C., Volchenkov, G. V., & Jensen, P. A. (2021). Antimicrobial drug resistance and infection prevention/control: lessons from tuberculosis. *International Journal of Infection Control*, *17*.

Chelkeba, L., Fanta, K., Mulugeta, T., & Melaku, T. (2022). Bacterial profile and antimicrobial resistance patterns of common bacteria among pregnant women with bacteriuria in Ethiopia: a systematic review and meta-analysis. *Archives of Gynecology and Obstetrics*, *306*(3), 663-686.

Cheung, C., Naughton, P. J., Dooley, J. S., Corcionivoschi, N., & Brooks, C. (2025). The spread of antimicrobial resistance in the aquatic environment from faecal pollution: a scoping review of a multifaceted issue. *Environmental Monitoring and Assessment*, *197*(4), 467.

Coque, T. M., Cantón, R., Pérez-Cobas, A. E., Fernández-de-Bobadilla, M. D., & Baquero, F. (2023). Antimicrobial resistance in the global health network: known unknowns and challenges for efficient responses in the 21st century. *Microorganisms*, *11*(4), 1050.

Cormontagne, D., Rigourd, V., Vidic, J., Rizzotto, F., Bille, E., & Ramarao, N. (2021). Bacillus cereus Induces Severe Infections in Preterm Neonates: Implication at the Hospital and Human Milk Bank Level. *Toxins (Basel)*, *13*(2). https://doi.org/10.3390/toxins13020123

Costa, B. O., Cardoso, M. H., & Franco, O. L. (2020). Development of peptides that inhibit aminoglycoside-modifying enzymes and β-lactamases for control of resistant bacteria. *Current Protein and Peptide Science*, *21*(10), 1011-1026.

Cowen, L. E., Sanglard, D., Howard, S. J., Rogers, P. D., & Perlin, D. S. (2015). Mechanisms of antifungal drug resistance. *Cold Spring Harbor perspectives in medicine*, *5*(7), a019752.

Dadgostar, P. (2019). Antimicrobial resistance: implications and costs. *Infection and drug resistance*, 3903-3910.

Darby, E. M., Trampari, E., Siasat, P., Gaya, M. S., Alav, I., Webber, M. A., & Blair, J. M. (2023). Molecular mechanisms of antibiotic resistance revisited. *Nature Reviews Microbiology*, *21*(5), 280-295.

DeMaio, A., Mehrotra, S., Sambamurti, K., & Husain, S. (2022). The role of the adaptive immune system and T cell dysfunction in neurodegenerative diseases. *Journal of Neuroinflammation*, *19*(1), 251.

Denkinger, C. M., Grant, A. D., Denkinger, M., Gautam, S., & D'Agata, E. M. (2013). Increased multi-drug resistance among the elderly on admission to the hospital--a 12-year surveillance study. *Arch Gerontol Geriatr*, *56*(1), 227-230. https://doi.org/10.1016/j.archger.2012.05.006

Desai, A. N., Mohareb, A. M., Hauser, N., & Abbara, A. (2022). Antimicrobial resistance and human mobility. *Infection and drug resistance*, 127-133.

Di Franco, S., Alfieri, A., Pace, M. C., Sansone, P., Pota, V., Fittipaldi, C., Fiore, M., & Passavanti, M. B. (2021). Blood stream infections from MDR bacteria. *Life*, *11*(6), 575.

Dirjayanto, V. J., Lazarus, G., Geraldine, P., Dyson, N. G., Triastari, S. K., Anjani, J. V., Wisnu, N. K., & Sugiharta, A. J. (2025). Efficacy of telemedicine-based antimicrobial stewardship program to combat antimicrobial resistance: A systematic review and meta-analysis. *Journal of Telemedicine and Telecare*, *31*(5), 615-627.

Domingo, E., García-Crespo, C., Lobo-Vega, R., & Perales, C. (2021). Mutation rates, mutation frequencies, and proofreading-repair activities in RNA virus genetics. *Viruses*, *13*(9), 1882.

IEER
Institute for Excellence in Education & Research

Dunachie, S. J., Day, N. P., & Dolecek, C. (2020). The challenges of estimating the human global burden of disease of antimicrobial resistant bacteria. *Current Opinion in Microbiology*, *57*, 95-101.

Economou, V., & Gousia, P. (2015). Agriculture and food animals as a source of antimicrobial-resistant bacteria. *Infection and drug resistance*, 49-61.

El-Khoury, C., Mansour, E., Yuliandra, Y., Lai, F., Hawkins, B. A., Du, J. J., Sundberg, E. J., Sluis-Cremer, N., Hibbs, D. E., & Groundwater, P. W. (2022). The role of adjuvants in overcoming antibacterial resistance due to enzymatic drug modification. *RSC Medicinal Chemistry*, *13*(11), 1276-1299.

Flensburg, J., & Sköld, O. (1987). Massive overproduction of dihydrofolate reductase in bacteria as a response to the use of trimethoprim. *European journal of biochemistry*, *162*(3), 473-476.

Fletcher-Miles, H., Gammon, J., Williams, S., & Hunt, J. (2020). A scoping review to assess the impact of public education campaigns to affect behavior change pertaining to antimicrobial resistance. *American Journal of Infection Control*, *48*(4), 433-442.

Fuller, W., Kapona, O., Aboderin, A. O., Adeyemo, A. T., Olatunbosun, O. I., Gahimbare, L., & Ahmed, Y. A. (2023). Education and awareness on antimicrobial resistance in the WHO African region: a systematic review. *Antibiotics*, *12*(11), 1613.

Galgano, M., Pellegrini, F., Catalano, E., Capozzi, L., Del Sambro, L., Sposato, A., Lucente, M. S., Vasinioti, V. I., Catella, C., & Odigie, A. E. (2025). Acquired bacterial resistance to antibiotics and resistance genes: from past to future. *Antibiotics*, *14*(3), 222.

Gheorghe, A. (2024). THE NATIONAL-LEVEL ECONOMIC BURDEN OF ANTIMICROBIAL RESISTANCE-A REVIEW OF AVAILABLE DATA. *Romanian Archives of Microbiology & Immunology*, *83*(1).

Ghoshal, A., Mallick, J., Sarkar, S., Ghosh, S., Ghosh, B., & Sarkar, S. (2023). Efflux pumps in antimicrobial resistance mechanism, regulation and therapeutic implications. *J Adv Zool*.

Gilham, E. L., Pearce-Smith, N., Carter, V., & Ashiru-Oredope, D. (2024). Assessment of global antimicrobial resistance campaigns conducted to improve public awareness and antimicrobial use behaviours: a rapid systematic review. *BMC Public Health*, *24*(1), 396.

Gomez, G. E., Hamer, M., Regiart, M. D., Tortella, G. R., Seabra, A. B., Soler Illia, G. J., & Fernández-Baldo, M. A. (2024). Advances in nanomaterials and composites based on mesoporous materials as antimicrobial agents: relevant applications in human health. *Antibiotics*, *13*(2), 173.

Grudlewska-Buda, K., Bauza-Kaszewska, J., Wiktorczyk-Kapischke, N., Budzyńska, A., Gospodarek-Komkowska, E., & Skowron, K. (2023). Antibiotic resistance in selected emerging bacterial foodborne pathogens—an issue of concern? *Antibiotics*, *12*(5), 880.

Haenni, M., Dagot, C., Chesneau, O., Bibbal, D., Labanowski, J., Vialette, M., Bouchard, D., Martin-Laurent, F., Calsat, L., & Nazaret, S. (2022). Environmental contamination in a high-income country (France) by antibiotics, antibiotic-resistant bacteria, and antibiotic resistance genes: Status and possible causes. *Environment international*, *159*, 107047.

Harkin, C. (2022). Systematic review and meta-analysis of plant-derived antimicrobials in WHO priority pathogens. *Int J Complement Alt Med*, *15*(2), 122-137.

Haruna, U. A., Eshun, G., Okesanya, O. J., Mohammed Elhadi, Y. A., & Lucero-prisno III, D. E. (2024). Antimicrobial resistance strains the wallet: Who pays when we hit the wall? *Microbes and Infectious Diseases*.

Hay, S. I., Rao, P. C., Dolecek, C., Day, N. P., Stergachis, A., Lopez, A. D., & Murray, C. J. (2018). Measuring and mapping the global burden of antimicrobial resistance. *BMC medicine*, *16*(1), 78.

Hazards, E. P. o. B., Koutsoumanis, K., Allende, A., Álvarez-Ordóñez, A., Bolton, D., Bover-Cid, S., Chemaly, M., Davies, R., De Cesare, A., & Herman, L. (2021). Role played by the environment in the emergence and spread of antimicrobial resistance (AMR) through the food chain. *Efsa Journal*, *19*(6), e06651.

Helmy, Y. A., Taha-Abdelaziz, K., Hawwas, H. A. E.-H., Ghosh, S., AlKafaas, S. S., Moawad, M. M., Saied, E. M., Kassem, I. I., & Mawad, A. M. (2023). Antimicrobial resistance and recent alternatives to antibiotics for the control of bacterial pathogens with an emphasis on foodborne pathogens. *Antibiotics*, *12*(2), 274.

Ho, C. S., Wong, C. T., Aung, T. T., Lakshminarayanan, R., Mehta, J. S., Rauz, S., McNally, A., Kintses, B., Peacock, S. J., & de la Fuente-Nunez, C. (2025). Antimicrobial resistance: a concise update. *The Lancet Microbe*, *6*(1).

Hoelzer, K., Wong, N., Thomas, J., Talkington, K., Jungman, E., & Coukell, A. (2017). Antimicrobial drug use in food-producing animals and associated human health risks: what, and how strong, is the evidence? *BMC veterinary research*, *13*(1), 211.

Holmes, C. L., Albin, O. R., Mobley, H. L., & Bachman, M. A. (2025). Bloodstream infections: mechanisms of pathogenesis and opportunities for intervention. *Nature Reviews Microbiology*, *23*(4), 210-224.

Horvat, O., & Kovačević, Z. (2025). Human and Veterinary Medicine Collaboration: Synergistic Approach to Address Antimicrobial Resistance Through the Lens of Planetary Health. *Antibiotics*, *14*(1), 38.

Huang, L., Wu, C., Gao, H., Xu, C., Dai, M., Huang, L., Hao, H., Wang, X., & Cheng, G. (2022). Bacterial multidrug efflux pumps at the frontline of antimicrobial resistance: an overview. *Antibiotics*, *11*(4), 520.

Hussain, A., Najeeb, A., & Ali, S. A. (2025). Antimicrobial Resistance: A Modern Plague. In *AI-Driven Breakthroughs in Antimicrobial Resistance* (pp. 27-74). IGI Global Scientific Publishing.

Ibrahim, M., Ahmad, F., Yaqub, B., Ramzan, A., Imran, A., Afzaal, M., Mirza, S. A., Mazhar, I., Younus, M., & Akram, Q. (2020). Current trends of antimicrobials used in food animals and aquaculture. In *Antibiotics and antimicrobial resistance genes in the environment* (pp. 39-69). Elsevier.

Indrayuni, I. G. A. A., Anteja, I. G. A. A. I., & Aryana, I. G. P. S. (2022). Multiple Antimicrobial-Resistant Bacteremia and Fungal Infection Pneumonia in Elderly Patient: A Case Study. *Indonesia Journal of Biomedical Science*, *16*(1), 24-27.

Ingelbeen, B. (2023). *Preventing and controlling outbreaks and AMR: From counting cases to monitoring risks* Utrecht University].

Ivanov, M., Ćirić, A., & Stojković, D. (2022). Emerging antifungal targets and strategies. *International Journal of Molecular Sciences*, *23*(5), 2756.

James, O. O. Investigating the Impact of Antimicrobial Resistance on Global Health and Combating Strategies.

Jansen, K. U., Knirsch, C., & Anderson, A. S. (2018). The role of vaccines in preventing bacterial antimicrobial resistance. *Nature medicine*, *24*(1), 10-19.

Juhas, M. (2015). Horizontal gene transfer in human pathogens. *Critical Reviews in Microbiology*, *41*(1), 101-108.

Kariuki, S., Kering, K., Wairimu, C., Onsare, R., & Mbae, C. (2022). Antimicrobial resistance rates and surveillance in sub-Saharan Africa: where are we now? *Infection and drug resistance*, 3589-3609.

Kausar, S., Said Khan, F., Ishaq Mujeeb Ur Rehman, M., Akram, M., Riaz, M., Rasool, G., Hamid Khan, A., Saleem, I., Shamim, S., & Malik, A. (2021). A review: Mechanism of action of antiviral drugs. *International journal of immunopathology and pharmacology*, *35*, 20587384211002621.

Khurana, A. (2019). Non-therapeutic antibiotic use and use of critically important antimicrobials in food-animals.

Kotwani, A., Joshi, J., & Kaloni, D. (2021). Pharmaceutical effluent: a critical link in the interconnected ecosystem promoting antimicrobial resistance. *Environmental Science and Pollution Research*, *28*(25), 32111-32124.

Kpokiri, E. E., Ladva, M., Dodoo, C. C., Orman, E., Aku, T. A., Mensah, A., Jato, J., Mfoafo, K. A., Folitse, I., & Hutton-Nyameaye, A. (2021). Knowledge, awareness and practice with antimicrobial stewardship programmes among healthcare providers in a Ghanaian tertiary hospital. *Antibiotics*, *11*(1), 6.

Kuchay, R. A. H. (2024). Novel and emerging therapeutics for antimicrobial resistance: A brief review. *Drug Discoveries & Therapeutics*, *18*(5), 269-276.

Kumar, S., Chaudhary, M., Yadav, M., & Kumar, V. (2020). Global surveillance programs on antimicrobial resistance. In *Sustainable Agriculture Reviews 46: Mitigation of Antimicrobial Resistance Vol 1 Tools and Targets* (pp. 33-58). Springer.

Kumavath, R., Gupta, P., Tatta, E. R., Mohan, M., Salim, S. A., & Busi, S. (2025). Unraveling the role of Mobile Genetic Elements (MGEs) in Antibiotic Resistance transmission and defending strategies in Bacteria. *Frontiers in Systems Biology*, *5*, 1557413.

Lawal, O. P., Ahmed, N. K., Ilesanmi, T. A., Anthony, G. I., Nwosu, S. N., Ogungbemiro, F. O., Olaide, Z., Adeniyi, M. M., Okoye, U. L., & Olufunmilayo, A. M. (2024). The impact of antimicrobial resistance on cancer treatment: A systematic review of current evidence and future directions. *Asian Journal of Research in Medical and Pharmaceutical Sciences*, *13*(4), 9-27.

Lee, Y., Robbins, N., & Cowen, L. E. (2023). Molecular mechanisms governing antifungal drug resistance. *npj Antimicrobials and Resistance*, *1*(1), 5.

Lepe, J., & Martínez-Martínez, L. (2022). Mecanismos de resistencia en bacterias gramnegativas. *Medicina intensiva*, *46*(7), 392-402.

Levison, M. E. (2002). Plasmid-mediated extended-spectrum β-lactamases in organisms other than Klebsiella pneumoniae and Escherichia coli: a hidden reservoir of transferable resistance genes. *Current Infectious Disease Reports*, *4*(3), 181-183.

Lewis, K. (2017). New approaches to antimicrobial discovery. *Biochemical pharmacology*, *134*, 87-98.

Lewnard, J. A., Charani, E., Gleason, A., Hsu, L. Y., Khan, W. A., Karkey, A., Chandler, C. I., Mashe, T., Khan, E. A., & Bulabula, A. N. (2024). Burden of bacterial antimicrobial resistance in low-income and middle-income countries avertible by existing interventions: an evidence review and modelling analysis. *The Lancet*, *403*(10442), 2439-2454.

Li, D., Ge, Y., Wang, N., Shi, Y., Guo, G., Zou, Q., & Liu, Q. (2023). Identification and characterization of a novel major facilitator superfamily efflux pump, SA09310, mediating tetracycline resistance in Staphylococcus aureus. *Antimicrobial agents and chemotherapy*, *67*(4), e01696-01622.

Li, M.-c., Lu, J., Lu, Y., Xiao, T.-y., Liu, H.-c., Lin, S.-q., Xu, D., Li, G.-l., Zhao, X.-q., & Liu, Z.-g. (2021). rpoB mutations and effects on rifampin resistance in Mycobacterium tuberculosis. *Infection and drug resistance*, 4119-4128.

MacPherson, E. E., Reynolds, J., Sanudi, E., Nkaombe, A., Mankhomwa, J., Dixon, J., & Chandler, C. I. (2022). Understanding antimicrobial use in subsistence farmers in Chikwawa District Malawi, implications for public awareness campaigns. *PLOS Global Public Health*, *2*(6), e0000314.

Marston, H. D., Dixon, D. M., Knisely, J. M., Palmore, T. N., & Fauci, A. S. (2016). Antimicrobial resistance. *Jama*, *316*(11), 1193-1204.

McEwen, S. A., & Collignon, P. J. (2018). Antimicrobial resistance: a one health perspective. *Antimicrobial resistance in bacteria from livestock and companion animals*, 521-547.

Mesa Varona, O., Chaintarli, K., Muller-Pebody, B., Anjum, M. F., Eckmanns, T., Norström, M., Boone, I., & Tenhagen, B.-A. (2020). Monitoring antimicrobial resistance and drug usage in the human and livestock sector and foodborne antimicrobial resistance in six European countries. *Infection and drug resistance*, 957-993.

Mohamed, A. H., Sheikh Omar, N. M., Osman, M. M., Mohamud, H. A., Eraslan, A., & Gur, M. (2022). Antimicrobial resistance and predisposing factors associated with catheter-associated UTI caused by uropathogens exhibiting multidrug-resistant patterns: a 3-year retrospective study at a tertiary hospital in Mogadishu, Somalia. *Tropical Medicine and Infectious Disease*, *7*(3), 42.

Mohanty, H., Pachpute, S., & Yadav, R. P. (2021). Mechanism of drug resistance in bacteria: efflux pump modulation for designing of new antibiotic enhancers. *Folia Microbiologica*, *66*(5), 727-739.

Morrison, L., & Zembower, T. R. (2020). Antimicrobial resistance. *Gastrointestinal Endoscopy Clinics*, *30*(4), 619-635.

Murray, C. J., Ikuta, K. S., Sharara, F., Swetschinski, L., Aguilar, G. R., Gray, A., Han, C., Bisignano, C., Rao, P., & Wool, E. (2022). Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. *The Lancet*, *399*(10325), 629-655.

Mustafa, Z. U., Khan, A. H., Salman, M., Syed Sulaiman, S. A., & Godman, B. (2022). Antimicrobial Utilization among Neonates and Children: A Multicenter Point Prevalence Study from Leading Children's Hospitals in Punjab, Pakistan. *Antibiotics (Basel)*, *11*(8). https://doi.org/10.3390/antibiotics11081056

Muteeb, G., Rehman, M. T., Shahwan, M., & Aatif, M. (2023). Origin of antibiotics and antibiotic resistance, and their impacts on drug development: A narrative review. *Pharmaceuticals*, *16*(11), 1615.

Naghavi, M., Vollset, S. E., Ikuta, K. S., Swetschinski, L. R., Gray, A. P., Wool, E. E., Aguilar, G. R., Mestrovic, T., Smith, G., & Han, C. (2024). Global burden of bacterial antimicrobial resistance 1990–2021: a systematic analysis with forecasts to 2050. *The Lancet*, *404*(10459), 1199-1226.

Naylor, N. R., Atun, R., Zhu, N., Kulasabanathan, K., Silva, S., Chatterjee, A., Knight, G. M., & Robotham, J. V. (2018). Estimating the burden of antimicrobial resistance: a systematic literature review. *Antimicrobial Resistance & Infection Control*, *7*(1), 58.

Ngong, I. N., Fru-Cho, J., Yung, M. A., & Akoachere, J.-F. K. T. (2021). Prevalence, antimicrobial susceptibility pattern and associated risk factors for urinary tract infections in pregnant women attending ANC in some integrated health centers in the Buea Health District. *BMC Pregnancy and Childbirth*, *21*(1), 673.

Obolski, U., Kassem, E., Na'amnih, W., Tannous, S., Kagan, V., & Muhsen, K. (2021). Unnecessary antibiotic treatment of children hospitalised with respiratory syncytial virus (RSV) bronchiolitis: risk factors and prescription patterns. *Journal of global antimicrobial resistance*, *27*, 303-308.

Ojeda, A., Akinsuyi, O., McKinley, K. L., Xhumari, J., Triplett, E. W., Neu, J., & Roesch, L. F. W. (2024). Increased antibiotic resistance in preterm neonates under early antibiotic use. *mSphere*, *9*(10), e0028624. https://doi.org/10.1128/msphere.00286-24

Oliveira, M., Antunes, W., Mota, S., Madureira-Carvalho, Á., Dinis-Oliveira, R. J., & Dias da Silva, D. (2024). An overview of the recent advances in antimicrobial resistance. *Microorganisms*, *12*(9), 1920.

Paiva Macedo, J. d., & Dias, V. C. (2024). Antifungal resistance: why are we losing this battle? *Future Microbiology*, *19*(11), 1027-1040.

Pallett, S. J., Boyd, S. E., O'Shea, M. K., Martin, J., Jenkins, D. R., & Hutley, E. J. (2023). The contribution of human conflict to the development of antimicrobial resistance. *Communications medicine*, *3*(1), 153.

Patnool, R. B., Wadhwani, A., Balasubramaniam, V., & Ponnusankar, S. (2022). Antimicrobial Resistance and Implications: Impact on Pregnant Women with Urinary Tract Infections. *J Pure Appl Microbiol*, *16*(2), 769-781.

Peng, B., Li, H., & Peng, X.-x. (2023). Call for next-generation drugs that remove the uptake barrier to combat antibiotic resistance. *Drug Discovery Today*, *28*(10), 103753.

Phodha, T., Riewpaiboon, A., Malathum, K., & Coyte, P. C. (2019). Excess annual economic burdens from nosocomial infections caused by multi-drug resistant bacteria in Thailand. *Expert Review of Pharmacoeconomics & Outcomes Research*, *19*(3), 305-312.

Ponzo, E., De Gaetano, S., Midiri, A., Mancuso, G., Giovanna, P., Giuliana, D., Zummo, S., & Biondo, C. (2024). The antimicrobial resistance pandemic is here: implementation challenges and the need for the one health approach. *Hygiene*, *4*(3), 297-316.

Prestinaci, F., Pezzotti, P., & Pantosti, A. (2015). Antimicrobial resistance: a global multifaceted phenomenon. *Pathogens and global health*, *109*(7), 309-318.

Rajesh, A., Mohanan, H., & Thomas, R. P. (2021). A Review on Antimicrobial Stewardship Programs in Multiple Care Settings. *J Pharm Res Int*, 264-270.

Rajkhowa, A., & Thursky, K. (2020). Awareness of antimicrobial resistance in the community: the role of the WHO in addressing consumer information needs. *Journal of Consumer Health on the Internet*, *24*(4), 391-406.

Rather, I. A., Kim, B.-C., Bajpai, V. K., & Park, Y.-H. (2017). Self-medication and antibiotic resistance: Crisis, current challenges, and prevention. *Saudi journal of biological sciences*, *24*(4), 808-812.

Rony, M. K. K., Sharmi, P. D., & Alamgir, H. M. (2023). Addressing antimicrobial resistance in low and middle-income countries: overcoming challenges and implementing effective strategies. *Environmental Science and Pollution Research*, *30*(45), 101896-101902.

Roudbary, M., Vahedi-Shahandashti, R., Santos, A. L. S. d., Roudbar Mohammadi, S., Aslani, P., Lass-Flörl, C., & Rodrigues, C. F. (2022). Biofilm formation in clinically relevant filamentous fungi: a therapeutic challenge. *Critical Reviews in Microbiology*, *48*(2), 197-221.

Roy, S., Malla, S., Dekari, D., & Choudhury, T. G. (2025). One Health Approach: Human, Environment, and Animal Health. In *Management of Fish Diseases* (pp. 281-297). Springer.

Rudnick, W., Mukhi, S. N., Reid-Smith, R. J., German, G. J., Nichani, A., & Mulvey, M. R. (2022). Overview of Canada's Antimicrobial Resistance Network (AMRNet): A data-driven One Health approach to antimicrobial resistance surveillance. *Canada Communicable Disease Report*, *48*(11-12), 522.

Sadeghi, F., Rajabi, E., Ghanbari, Z., Fattahniya, S., Samiee, R., Akhavan, M., Salehi, M., & Shafaati, M. (2025). Antimicrobial Resistance in Immunocompromised Outpatients: A Narrative Review of Current Evidence and Challenges. *Pharmacoepidemiology*, *4*(4), 21. https://www.mdpi.com/2813-0618/4/4/21

Safdar, N., Saleem, S., Salman, M., Tareq, A. H., Ishaq, S., Ambreen, S., Hameed, A., Habib, M. B., & Ali, T. M. (2025). Economic burden of antimicrobial resistance on patients in Pakistan. *Frontiers in Public Health*, *13*, 1481212.

Saga, T., & Yamaguchi, K. (2009). History of antimicrobial agents and resistant bacteria. *Jmaj*, *52*(2), 103-108.

Sardana, K., Sharath, S., Khurana, A., & Ghosh, S. (2023). An update on the myriad antifungal resistance mechanisms in dermatophytes and the place of experimental and existential therapeutic agents for Trichophyton complex implicated in tinea corporis and cruris. *Expert Review of Anti-infective Therapy*, *21*(9), 977-991.

Sartelli, M., Coccolini, F., Kluger, Y., Agastra, E., Abu-Zidan, F. M., Abbas, A. E. S., Ansaloni, L., Adesunkanmi, A. K., Augustin, G., & Bala, M. (2022). WSES/GAIS/WSIS/SIS-E/AAST global clinical pathways for patients with skin and soft tissue infections. *World Journal of Emergency Surgery*, *17*(1), 3.

Sharma, S., Satyaseela, M. P., Burri, R. R., Palakodeti, R., & Pamarthy, D. (2025). Combating Antimicrobial Resistance: Role of Key Stakeholders with Focus on the Pharmaceutical Sector. *Pharmaceutical Medicine*, 1-31.

Shen, Z., Tang, C. M., & Liu, G.-Y. (2022). Towards a better understanding of antimicrobial resistance dissemination: what can be learnt from studying model conjugative plasmids? *Military Medical Research*, *9*(1), 3.

Singh, A., Singh, K., Sharma, A., Kaur, K., Chadha, R., & Bedi, P. M. S. (2023). Recent advances in antifungal drug development targeting lanosterol 14α-demethylase (CYP51): A comprehensive review with structural and molecular insights. *Chemical Biology & Drug Design*, *102*(3), 606-639.

Singh, S., Sharma, P., Pal, N., Sarma, D. K., Tiwari, R., & Kumar, M. (2024). Holistic one health surveillance framework: synergizing environmental, animal, and human determinants for enhanced infectious disease management. *ACS Infectious Diseases*, *10*(3), 808-826.

Skender, K., Machowska, A., Khare, S., Singh, V., Lundborg, C. S., & Sharma, M. (2025). Antibiotic prescribing practices, perceived constraints, and views on antimicrobial resistance among general and orthopedic surgeons in central India. *Scientific Reports*, *15*(1), 25099.

Smyk, J. M., Szydłowska, N., Szulc, W., & Majewska, A. (2022). Evolution of influenza viruses—drug resistance, treatment options, and prospects. *International Journal of Molecular Sciences*, *23*(20), 12244.

Soraci, L., Cherubini, A., Paoletti, L., Filippelli, G., Luciani, F., Laganà, P., Gambuzza, M. E., Filicetti, E., Corsonello, A., & Lattanzio, F. (2023). Safety and tolerability of antimicrobial agents in the older patient. *Drugs & aging*, *40*(6), 499-526.

Stevanovic, M., Boukéké-Lesplulier, T., Hupe, L., Hasty, J., Bittihn, P., & Schultz, D. (2022). Nutrient gradients mediate creation of highly resistant layers in structured microbial populations during antibiotic exposures. *bioRxiv*, 2022.2002. 2002.478895.

Sturrock, S., Sadoo, S., Nanyunja, C., & Le Doare, K. (2023). Improving the Treatment of Neonatal Sepsis in Resource-Limited Settings: Gaps and Recommendations. *Res Rep Trop Med*, *14*, 121-134. https://doi.org/10.2147/rrtm.S410785

Sulis, G., Sayood, S., & Gandra, S. (2022). Antimicrobial resistance in low-and middle-income countries: current status and future directions. *Expert Review of Anti-infective Therapy*, *20*(2), 147-160.

Sulis, G., Sayood, S., Katukoori, S., Bollam, N., George, I., Yaeger, L. H., Chavez, M. A., Tetteh, E., Yarrabelli, S., & Pulcini, C. (2022). Exposure to World Health Organization's AWaRe antibiotics and isolation of multidrug resistant bacteria: a systematic review and meta-analysis. *Clinical Microbiology and Infection*, *28*(9), 1193-1202.

Tang, K. W. K., Millar, B. C., & Moore, J. E. (2023). Antimicrobial resistance (AMR). *British journal of biomedical science*, *80*, 11387.

Tarin-Pello, A., Suay-Garcia, B., & Perez-Gracia, M.-T. (2022). Antibiotic resistant bacteria: current situation and treatment options to accelerate the development of a new antimicrobial arsenal. *Expert Review of Anti-infective Therapy*, *20*(8), 1095-1108.

Tollefson, L., & Karp, B. E. (2004). Human health impact from antimicrobial use in food animals. *Medecine et maladies infectieuses*, *34*(11), 514-521.

Tomczyk, S., Taylor, A., Brown, A., De Kraker, M. E., El-Saed, A., Alshamrani, M., Hendriksen, R. S., Jacob, M., Löfmark, S., & Perovic, O. (2021). Impact of the COVID-19 pandemic on the surveillance, prevention and control of antimicrobial resistance: a global survey. *Journal of Antimicrobial Chemotherapy*, *76*(11), 3045-3058.

Totaro, V., Guido, G., Cotugno, S., De Vita, E., Asaduzzaman, M., Patti, G., Segala, F. V., Putoto, G., Frallonardo, L., & Farkas, F. B. (2025). Antimicrobial Resistance in Sub-Saharan Africa: A Comprehensive Landscape Review. *The American Journal of Tropical Medicine and Hygiene*, *1*(aop).

Ture, Z., İskender, G., Şahinoğlu, M. S., Özkara, E. B., Kalem, A. K., Eren, E. E., Ürkmez, F. Y., Çetin, S., Azak, E., & Erdem, İ. (2025). Epidemiology and prognosis of sepsis in cancer patients: A multicenter prospective observational study. *The American Journal of the Medical Sciences*.

Vaishampayan, A., & Grohmann, E. (2021). Antimicrobials functioning through ros-mediated mechanisms: Current insights. *Microorganisms*, *10*(1), 61.

Vlad, T., Eftenoiu, A.-E., Voinescu, A., Musuroi, S. I., Musuroi, C., Moatar, A. E., Vlad, D. C., Trandafir, A., Vlad, C. S., & Cobec, I. M. (2025). Antimicrobial Resistance in Maternal Infections During Pregnancy. *Biomedicines*, *13*(4), 777.

Wachino, J. i. (2025). Horizontal Gene Transfer Systems for Spread of Antibiotic Resistance in Gram-Negative Bacteria. *Microbiology and Immunology*, *69*(7), 367-376.

Wang, C., Wei, X., Zhong, L., Chan, C.-L., Li, H., & Sun, H. (2025). Metal-based approaches for the fight against antimicrobial resistance: Mechanisms, opportunities, and challenges. *Journal of the American Chemical Society*, *147*(15), 12361-12380.

Wilson, C., & Seaton, R. A. (2024). Antimicrobial Stewardship in the Frail Elderly. *British Journal of Hospital Medicine*, *85*(11), 1-12.

Winter, M., Buckling, A., Harms, K., Johnsen, P. J., & Vos, M. (2021). Antimicrobial resistance acquisition via natural transformation: context is everything. *Current Opinion in Microbiology*, *64*, 133-138.

Wozniak, T. M., Dyda, A., Merlo, G., & Hall, L. (2022). Disease burden, associated mortality and economic impact of antimicrobial resistant infections in Australia. *The Lancet Regional Health–Western Pacific*, *27*.

Ya, K. Z., Win, P. T. N., Bielicki, J., Lambiris, M., & Fink, G. (2023). Association between antimicrobial stewardship programs and antibiotic use globally: a systematic review and meta-analysis. *JAMA network open*, *6*(2), e2253806-e2253806.

Yadav, S. K., Dandu, H., Gupta, P., Nischal, A., & Atam, V. (2022). Antimicrobial resistance and antimicrobial stewardship program: Need of the hour. *Journal of Internal Medicine of India*, *16*(2), 21-25.

Yeta, K. I., Michelo, C., & Jacobs, C. (2021). Antimicrobial resistance among pregnant women with urinary tract infections attending antenatal clinic at Levy Mwanawasa University Teaching Hospital (LMUTH), Lusaka, Zambia. *International journal of microbiology*, *2021*(1), 8884297.

Yeta, K. I., Michelo, C., & Jacobs, C. (2021). Antimicrobial Resistance among Pregnant Women with Urinary Tract Infections Attending Antenatal Clinic at Levy Mwanawasa University Teaching Hospital (LMUTH), Lusaka, Zambia. *Int J Microbiol*, *2021*, 8884297. https://doi.org/10.1155/2021/8884297

Zajac-Spychala, O., Kampmeier, S., Lehrnbecher, T., & Groll, A. H. (2022). Infectious complications in paediatric haematopoetic cell transplantation for acute lymphoblastic leukemia: current status. *Frontiers in pediatrics*, *9*, 782530.

Zakeri, B., & Lu, T. K. (2013). Synthetic biology of antimicrobial discovery. *ACS synthetic biology*, *2*(7), 358-372.

Zhan, X.-Y., & Zhu, Q.-Y. (2018). Evolution of methicillin-resistant Staphylococcus aureus: Evidence of positive selection in a penicillin-binding protein (PBP) 2a coding gene mecA. *Infection, Genetics and Evolution*, *59*, 16-22.

Zhang, L., Tian, X., Sun, L., Mi, K., Wang, R., Gong, F., & Huang, L. (2024). Bacterial efflux pump inhibitors reduce antibiotic resistance. *Pharmaceutics*, *16*(2), 170.

Zhou, W., Wen, Z., Zhu, W., Gu, J., Wei, J., Xiong, H., & Wang, W. (2025). Factors associated with clinical antimicrobial resistance in China: a nationwide analysis. *Infectious Diseases of Poverty*, *14*(1), 27.

Zulfkar, Q., Humaira, A., Mohd, A. D., & Afshana, Q. (2025). THE GROWING THREAT OF ANTIBIOTIC RESISTANCE: MECHANISMS, CAUSES, CONSEQUENCES, AND SOLUTIONS. *International Journal of Cognitive Neuroscience and Psychology*, *3*(3), 28-36.

IEER
Institute for Excellence in Education & Research