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Review Article

Antimicrobial Resistance: Current Trends and Future Strategies

Dr. Vaibhav V. Bhone, Dr. Dattaprasad Vikhe*, Gayatri Vyavhare, Prathamesh Ugale, Dr. Gaurao Damre

PRES's Pravara Rural College of Pharmacy, Pravaranagar, Maharashtra, India-413736.

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ABSTRACT

Antimicrobial resistance as emerged as critical as global challenges, threatening the effectiveness of antibiotics on other antimicrobial agents use to treat infectious disease. The improper and excessive use of antimicrobials in human medicine, animal agriculture and environmental sectors has accelerated the development and spread of non-susceptible microorganism. This review highlights the current trends and future strategies in AMR, including increasing resistance among bacterial sepsis, global antibiotic consumption patterns and increasing mortality linked to drug resistant-infection. The study also explores the underlying mechanisms of resistance such as, genetic mutations and horizontal gene transfer. key contributing factors- including poor infection control, lake of clean water, sanitation and inadequate surveillance are discussed. There is an urgent need for countries to work together, use antibiotic more carefully improving infection control and develop new tests and treatments to fight antimicrobial resistance (AMR). This review also highlights future solutions and stresses the important of the one health approach which connect humans, animals and environmental health.

INTRODUCTION

The increasing prevalence of antimicrobial resistance has become a major concern for global health authorities AMR occurs when micro-organism such as bacteria ,virus fungi and parasite evolve to resist the effect of medication making infection more difficult to treat this phenomenon not only compromises the effectiveness of standard treatment but also increase the risk of disease spread , severe illness ,and also death(1–3). The misuse of antimicrobials across human, vertinary, and environmental domains accelerates resistance AMR was directly linked to an estimated 1.27 million deaths globally in 2019 and contributed to almost 5 million more Without timely intervention, AMR may reach to 10 million by 2050, surpassing cancer as a cause of death17.

***Corresponding Author:** Dr. Dattaprasad Vikhe

Address: *PRES's Pravara Rural College of Pharmacy, Pravaranagar, Maharashtra, India-413736.*

Email ✉: prasadvikhepatil@gmail.com

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In the United States, AMR infections affect over 2 million people each year, resulting in more than 23,000 deaths and $55 billion in healthcare costs25. The situation is similarly dire in Europe, where multidrug-resistant microbial infections claim approximately 33,000 lives annually and incur over €1.5 billion in healthcare expenditure and productivity losses etic changes in pathogens(2). The scope of the challenge includes understanding current trends in AMR, the underlying mechanisms of resistance, and future strategies to combat it(4). Factors such as horizontal gene transfer, spontaneous mutation, and selective pressure from antibiotic overuse contribute to the development and spread of AMR(2). Furthermore, interdependent factors related to healthcare, agriculture, pharmaceuticals, and waste management influence AMR, making it a complex public health concern(5). Addressing AMR requires a collaborative, multi-faceted approach involving governments, private industries, and non-governmental organizations(4). This includes improving hygiene practices, using narrow-spectrum antibiotics, implementing infection prevention and control programs, and developing national action plans to combat AMR._Global initiatives, such as the WHO's efforts to promote coordinated action and the CDC's AMR Challenge, aim to limit antimicrobial misuse, fund research, and ensure access to necessary antimicrobials in developing nations(2). Surveillance systems are being established to track AMR, guide prevention strategies, and report results at local and global levels. By increasing capacity to track AMR and strengthening healthcare systems, countries can improve their response to resistant infections and enhance patient safety(4).

Current trends in antimicrobial resistance

Recent surveillance data from initiatives liked Global Antimicrobials Resistance Surveillance System. (GLASS), reveals increasing resistance rates among common pathogens3. According to the 2022 GLASS report, in 76 surveyed countries, the median resistance showed that 42%of E.Coli isolates were resistant to third generation cephalosporin's, while 35%of Staphylococcus aureus isolates were resistant to methicillin. In addition, by 2020, about 20%of urinary tract infections caused by E-coli showed resistance to commonly prescribed antibiotics such as ampicillin, co-trimoxazole and fluroquinolone. The increase in resistance to vital antibiotics. As these critical drugs become less effective, the possibility of facing untreatable infection become more pronounced. The Organization for Economic Cooperation and Development (OECD) has projected the resistance to last line antibiotics will double by 2035, compared to rates observed in 2005, stressing the importance of intensified stewardship efforts are expanded global monitoring. The number of deaths due to Carbapenem-resistant gram-negative bacteria have climb substantially, from 50,900 cases in 1990 to 127,000 cases in 2021. Future forecasts estimate that, by 2050, antimicrobial resistance will lead 1.91 million deaths annually in addition to 8.22 million deaths related to infection complicated by resistance. Specific settings, such as hospitals, have seen increases in antimicrobial-resistant, hospital-onset infections, particularly during the COVID-19 pandemic(1). The rise in antibiotic consumption globally is a significant driver of AMR. A recent study analysing pharmaceutical sales data from 67 countries between 2016 to 2023 found 16.3 %increase in consumption of antibiotic, rising from 29.5 billion to 34.3 billion define daily dose DDDs. This corresponds to 10.2 %increase in the usage rate, from 13.7 to 15.2 DDDs per 1,000 people per day(6). Projections estimate that antibiotic use could reach to 75.1 billion DDDs by 2030 - a52.3%rise. Alarmingly resistance to WHO-designated critically important antimicrobial has resulted in more in deaths in 2022 compared to 1990bfor six out of seven high priority pathogen. Deaths due to methicillin-resistant *S. aureus* (MRSA) increased the most globally, leading directly to 130,000 deaths in 2021 – more than doubling from 57,200 in 1990. Among Gram-negative bacteria, resistance to carbapenems increased more than any other type of antibiotic, from 127,000 in 1990 to 216,000 in 2021. Modelling suggests that improving overall infection care and access to antibiotics could prevent 92 million deaths between 2025 and 2050, with the greatest benefits in South Asia, sub-Saharan Africa, and parts of Southeast Asia, East Asia, and Oceania(7).Addressing this escalating crisis requires prioritizing the reduction of inappropriate antibiotic use, improving infection prevention and control measures, and increasing childhood vaccination coverage(6). The World Health Organization (WHO) emphasizes the pressing need for new, innovative antibacterial agents for serious infections and to replace those becoming ineffective due to widespread use. Concerted efforts are essential to steer antibacterial research and development to better counter the ever-growing threat of antimicrobial resistance(8)

Mechanisms of Antimicrobial Resistance

Bacteria utilize a variety of strategies to evade effect of antimicrobial agents , including target site modifications, decreased influx, increased efflux pumps, and enzymatic inactivation of antibacterials(9). These resistance mechanisms are driven by genetic changes, such as mutations and horizontal gene transfer, and influenced by selection pressure from antimicrobial use, suboptimal dosing, and environmental factors(10)

Mechanisms of Antibacterial Resistance:

Target Site Modifications: Alterations in the bacterial target can prevent antibiotics from binding effectively. This can involve mutations in genes encoding the target protein, leading to structural changes that reduce the antibiotic's affinity. An example is methicillin resistance in *Staphylococcus aureus* (MRSA), where the bacteria acquire the *mecA* gene and produce a new penicillin-binding protein with low affinity for β-lactam antibiotics(9). Another instance is seen in glycopeptide resistance, where bacteria modify peptidoglycan precursors to prevent antibiotics from associating with the target(10).

Decreased Influx: Reduced membrane permeability can limit the entry of antibiotics into the bacterial cell(9). Alteration in the structure or composition of the bacterial membrane can hinder the entry of antibiotics, thereby reducing the drugs concentration inside the cell. this decrease permeability is known resistance strategies for various antibiotic classes such as aminoglycosides , chloramphenicol, and quinolones(11).

Efflux Pumps: Efflux system helps bacteria resist antibiotics by pumping them out of the cell before they reach their target size. These pumps are often capable of transporting a wide range of substances, including nutrients and signalling compound. Mutation that up regulate this pumps contribute to increased resistance(9).

Genetic Mechanisms in AMR

Mutations: Alteration in bacterial DNA can result resistance to antibiotic. These genetic change can affect the expression of efflux system or , reduce membrane permeability in some cases chromosomal mutation may cause cross resistance, leading to reduce susceptibility to multiple antibiotic classes(12).

Horizontal Gene Transfer: Bacteria are capable of exchanging genetic material including resistance genes through process known as horizontal gene transfer(10). This transfer can occur in several ways

A. **Transformation (**uptake of free DNA from surrounding)
B. **Transduction (**gene transfer via bacteriophages) and
C. **Conjugation (**direct DNA transfer between bacteria)(11).

Role of selection pressure in AMR

Antimicrobial Use:_The application of antibiotic create selective pressure ,which favours the servile of resistant organism .overuse and inappropriate use of antimicrobial in health care, vertinary medicine, and agriculture significantly speed up the emergency and dissemination of resistance

Environmental Factors:___ Environmental contamination, such as antibiotics residue in soil water and waste water can also exert selective pressure on bacterial communities.

Self-Resistance Mechanisms: Bacteria that naturally produce antibiotic often possesses internal resistance system to protect themselves. Thee self-resistance mechanism include modifying or degrading the antibiotic .utilizing efflux pumps altering targets, sequestering the drug or bypassing its action altogether(10).

Key Drivers behind the Spread of Antimicrobial Resistance

The use of antibiotics in animal agriculture plays a substantial source role in the development of antimicrobial resistant infections both in human and animal. Excessive and improper application of these drug in, livestock , largely fuelled by increasing global composition of animal derived food , result in emergency of resistant genes within animal population (13). a large portion of these antimicrobials is excreted and metabolized from contributing to environmental population and fostering antimicrobial resistance (AMR) by applying selective pressure on microbial application(14).While antimicrobials are indispensable in vertinary practice for managing and preventing animal disease(15). However, using antimicrobials regularly to promote animal growth or as cheap option instead of maintaining proper hygiene is a serious issue(13). This practice contributes to AMR and can result in antimicrobial residues in foods, such as milk, meat, and eggs, potentially causing health-related issues, including allergic reactions, mutagenicity, and carcinogenicity(15).The spread of AMR from animals to humans is well-documented, especially for common foodborne pathogens resistant to quinolones, such as *Campylobacter* spp. and *Salmonella* spp(13). International travel and trade further disseminate resistant strains across borders. The interconnectedness of global supply chains allows for the rapid spread of resistant bacteria, making AMR a global challenge that requires international cooperation to address. Inadequate sanitation and hygiene practices, particularly in healthcare settings, exacerbate the problem(16). Poor hygiene and sanitation promote the spread of resistant bacteria, increasing the risk of infections in hospitals and other healthcare facilities. The lack of access to clean water, sanitation, and hygiene (WASH) services in many parts of the world further contributes to the spread of AMR. Livestock and poultry producers play a crucial role in reducing the development and spread of AMR. Key practices include working closely with veterinarians, maintaining animal health through good husbandry and biosecurity measures, using antibiotics and antifungals exactly as prescribed, and protecting workers through appropriate hygiene and safety measures(17). The implementation of global regulations to cap antimicrobial use, adherence to nutritional guidelines to reduce meat consumption, and the imposition of user fees on veterinary antimicrobial use are potential strategies to curb antimicrobial consumption in food animal production(13). Antimicrobial resistance genes (ARGs) can confer resistance to various major classes of antibiotics, including tetracyclines (*Tet*), sulphonamides (*Sul*), β-lactams (*bla*), macrolide-lincosamid-streptogramin B (MLSB) (*erm*), aminoglycosides (*aac*), fluoroquinolone, quinolone, florfenicol, chloramphenicol, and amphenicol (FCA) (*fca*), colistin (*mcr*), vancomycin (*van*), and multidrug (*mdr*). The most frequently detected ARG classes in livestock waste include *tet*, *sul*, *erm*, *fca*, and *bla*, which correspond to the major classes of antibiotics used in animal husbandry(18). Addressing AMR requires a multifaceted approach, including reducing inappropriate antibiotic use, improving infection prevention and control, developing new antibiotics, and implementing surveillance programs. Collaborative efforts involving governments, private industries, and non-governmental organizations are essential to combat this global threat effectively(13).

Impact of Antimicrobial Resistance:

Antimicrobial resistance (AMR) has serious effect on human health. It can make treatment less effective, cause longer hospital stays, and increase the risk of death (19). Infections caused by resistant bacteria have up to twice likely lead to complication compared to those caused by bacteria(20). One of the major result of AMR is the treatment doesn't work as expected(21). When infections are resistant to first-line antibiotics, healthcare providers must resort to alternative treatments, which are often more toxic, expensive, and less effective(20). These reliance on these alternatives can lead to serious side effects, such as organ failure, and prolong the duration of care and recovery, sometimes for months(22). In some cases, antimicrobial-resistant infections have no treatment options, leading to increased morbidity and mortality(22). Longer hospital stays are another significant consequence of AMR(23). Patients with resistant infections require more intensive care and may experience complications that prolong their hospital stay(1). This increased length of stay not only affects the patient's well-being but also places a burden on healthcare resources, increasing costs and reducing hospital activity(20). Higher mortality rates are a devastating outcome of AMR(23). Infections caused by resistant bacteria are more difficult to treat, leading to increased mortality. Globally, it is estimated that bacterial AMR was directly responsible for 1.27 million deaths in 2019 and contributed to 4.95 million deaths(1). In the United States, the Centres for Disease Control and Prevention (CDC) estimates that more than 2.8 million antimicrobial-resistant infections occur each year, resulting in more than 35,000 deaths(22). The challenges in treating resistant infections extend beyond the availability of effective antibiotics. The diagnostic process for identifying resistant infections can be lengthy and complex, appropriate treatment. Rapid and accurate diagnostics are essential for guiding antibiotic therapy and improving patient outcomes. However, the development and implementation of these diagnostics face several challenges, including cost, accessibility, and the need for specialized training and equipment(24). The economic burden of AMR on healthcare systems and society is substantial(20). Increased resource utilization, higher costs, and reduced hospital activity all contribute to the economic impact of AMR. The World Bank estimates that AMR could result in US$ 1 trillion in additional healthcare costs by 2050 and US$ 1 trillion to US$

3.4 trillion in gross domestic product (GDP) losses per year by 2030(1). In the United States, AMR infections cost the healthcare system billions of dollars each year(20). The negative impacts of antibacterial resistance extend beyond the direct effects on patients and healthcare systems. The rise of AMR also threatens many medical advances that rely on the ability to fight infections using antibiotics, including joint replacements, organ transplants, cancer therapy, and the treatment of chronic diseases like diabetes, asthma, and rheumatoid arthritis(22). As antibiotics become less effective, these procedures and treatments become riskier, potentially limiting their availability and effectiveness. Addressing the consequences of AMR requires a multifaceted approach, including reducing inappropriate antibiotic use, improving infection prevention and control, developing new antibiotics, and implementing surveillance programs. Collaborative efforts involving governments, private industries, and non-governmental organizations are essential to combat this global threat effectively(1). AMR has dire consequences for human health, leading to increased treatment failures, longer hospital stays, and higher mortality rates. As germs become more resistant, infections and illnesses, such as pneumonia and infectious diarrhoea, become harder to treat. Medical procedures like surgeries and cancer treatments also become riskier(25).When infections resist first-line antibiotics, healthcare providers must use more toxic, expensive, and less effective alternatives(26). These can cause serious side effects, such as organ failure, and prolong care and recovery, sometimes for months. In some cases, antimicrobial-resistant infections have no treatment options(22). Patients with resistant infections need more intensive care and may experience complications that prolong their hospital stay. This strains healthcare resources, increases costs, and reduces hospital activity. AMR also has disastrous impacts on healthcare costs. In the United States alone, antibiotic resistance could add about $1,400 to the hospital bill for treating patients with any bacterial infections. The CDC estimates that antibiotic resistance could add more than $2 billion every year. AMR may cost from $300 billion to more than $1 trillion annually by 2050 worldwide(27). AMR threatens medical advances that rely on the ability to fight infections using antibiotics, including joint replacements, organ transplants, cancer therapy, and the treatment of chronic diseases like diabetes, asthma, and rheumatoid arthritis. As antibiotics become less effective, these procedures and treatments become riskier, potentially limiting their availability and effectiveness(22). The WHO estimates that AMR could result in US$ 1 trillion additional healthcare costs by 2050, and US$ 1 trillion to US$ 3.4 trillion gross domestic product (GDP) losses per year by 2030.

Strategies to Combat Antimicrobial Resistance:

Antimicrobial stewardship programs (ASPs) are crucial for improving use of antimicrobial agents, which include antibiotics(28). These programs promote correct antimicrobial use, improve patient outcomes, reduce microbial resistance, and decrease the spread of infections caused by highly resistant organisms(29). ASPs guide health care professionals on how to use antimicrobials safely and efficiently, covering drug selection, dosing, how it's given and how long it should be used. The core aim of ASP's is to get the possible outcomes for patients while reducing problems like side effect or the rise of resistance(28). Strong infection and control IPC measure levels are vital in both hospital and communities to stop AMR from spreading. IPC efforts are economical as they reduce the spread of resistant micro-organism, which can grow easily in healthcare environment8. Using antibiotics the wrong way too often or when they are not needed is one of the biggest public health risk today. When bacteria get used to antibiotics, those medicines become useless. Patient with drug resistant infection often to be need to stay in hospital longer, face higher medical costs, and have greater dying chance from the infection(29).

Core Strategies of ASPs

When putting together on ASP, two main methods are essential:

Active intervention: usually done by clinical pharmacist with infectious disease expertise, working closely with a physician in the programme

Audit and feedback: Reviewing prescription and giving advice to doctors to improve antibiotic use. This might include limiting access to certain drugs or requiring approval before prescribing. Extra tools can be added depending on what's available locally. Educating health care staff is also key part of the programme, though on its own. Using clear clinical guidelines and care pathways can help manage common and severe infections more effectively(28).

Benefits of ASPs-

ASPs have several benefits, including:

- They help to reduce the emergence of organism that are resistant to multiple drugs (MDROs).
- They lower the chances of harmful side effect from medication like diarrhoea linked to antibiotics or kidney damage.
- Help to reduce hospital time.
- Reducing collateral damage, such as the development of *Clostridium difficile* colitis.
- Reducing healthcare costs(28).
- Improving patient outcomes.
- Reducing readmission rates.
- Reducing antibiotic resistance.

In one study, infections managed with the assistance of an ASP resulted in a 70% increase in infection cures and an 80% decrease in treatment failures(30).

The Role of IPC in Combating AMR

Infection prevention and control (IPC) is a practical approach to controlling the spread of AMR. IPC measures include:

- Hand hygiene
- Environmental cleaning
- Isolation precautions
- Vaccination

These measures help to prevent the transmission of resistant pathogens in healthcare settings and the community(31).

Other Considerations

Although ASPs mainly focus on drug resistance they also deal with other patient safety issues. For instance, *clostridium difficile* poses major risk in hospital but ASPs have been very helpful in controlling this infections(30). Antimicrobial stewardship programs (ASPs) are essential for optimizing the use of antimicrobial agents, which include antibiotics(28). These programs promote appropriate antimicrobial use, improve patient outcomes, reduce microbial resistance, and decrease the spread of infections caused by multidrug-resistant organisms(29). ASPs provide guidance for the safe and cost-effective use of antimicrobial agents, addressing the correct selection of agents, dosages, routes of administration, and duration of therapy. The main purpose of ASPs is to make treatment more effective while avoiding problems like side effects or antibiotic resistance(28). Robust infection prevention and control (IPC) strategies are crucial in healthcare settings and the community to control the spread of antimicrobial resistance (AMR). Strong IPC measures are cost-saving because AMR can thrive in healthcare(32). Using too many or the wrong antibiotics is a serious problem worldwide. Germs can become resistant, meaning the drugs no longer work. This can cause infections that last longer, cost more to treat, and are more dangerous(29).

Effectiveness of ASPs

Reduction in Antimicrobial Use: Studies have shown that ASPs are effective in reducing antimicrobial ingestion in both hospital and non-hospital settings(33). One study reported a 5.4% decrease in antimicrobials prescribed during the first year of the program, accounting for approximately 2 million fewer items(34). A systematic review and meta-analysis of 52 studies with more than 1.7 million patients found that ASPs were associated with a 10% reduction in antibiotic prescriptions and a 28% reduction in antibiotic consumption(33).

Cost Savings: ASPs have illustrated proven benefits through decreasing the cost of medications(35). A study in a long-term care facility estimated cumulative cost savings of 5.64 million SAR (US$1.50 million) due to the implementation of an ASP(34).

Reduction in Multidrug-Resistant Organisms (MDRO): ASPs can lead to a reduction in the rate of multidrug-resistant hospital-acquired infections (MDR-HAI). A study observed a large-size reduction in the MDR-HAI rate, notably in the ICU, where it declined from 3.22 per 1,000 patient days in 2015 to 1.14 per 1,000 patient days in 2020(34).

Optimizing Antibiotic Use: Antimicrobial Stewardship Programs (ASPs) help improve the proper use of antibiotics and reduce problems like *Clostridium difficile* infections and antibiotic resistance(36).

Improved Clinical Outcomes: Infections managed with the assistance of an ASP resulted in a 70% increase in infection cures and an 80% decrease in treatment failures.

Core Elements of ASPs: The CDC has outlined core elements for hospital ASPs, which include structural and procedural components associated with successful stewardship programs(36).These core elements aim to improve clinical outcomes and minimize harms by improving antibiotic prescribing(37).

Strategies and Interventions

Multidisciplinary Approach: ASPs are designed and led by a multidisciplinary team, including an infectious disease consultant, clinical pharmacists, a clinical microbiologist, and an infection control preventionist(34).

Interventions: Efforts to enhance antibiotic prescribing can be either strict requiring approval before prescribing or educational, such as training, feedback after prescribing, and audits.

"Time Out" Intervention: Reconsidering the continuing need for and choice of drug by using an antibiotic "time out" program may reduce unnecessary treatment(36).

WHO's Role

The World Health Organization (WHO) guides countries to develop and implement ASPs, recognizing them as one of the most cost-effective interventions to optimize the use of antimicrobial medicines, improve patient outcomes, and reduce antimicrobial resistance and healthcare-associated infections. The WHO supports various activities, including workshops, webinars, and the development of educational tools, to help countries achieve their antimicrobial stewardship goals World Health Organization (WHO) guides countries to develop and implement ASPs, recognizing them as one of the most cost-effective interventions to optimize the use of antimicrobial medicines, improve patient outcomes, and reduce antimicrobial resistance and healthcare-associated infections. The WHO supports various activities, including workshops, webinars, and the development of educational tools, to help countries achieve their antimicrobial stewardship goals(38).

The One Health Approach

Antimicrobial resistance (AMR) is a multifaceted global problem that affects human health, animal health, and the environment, requiring a comprehensive and collaborative approach to mitigate its spread(39). The interconnectedness of these domains is central to understanding and addressing AMR, as the misuse and overuse of antimicrobials in one sector can have cascading effects on others(40).

The One Health Approach to AMR

The "One Health" paradigm has emerged as a holistic strategy to combat AMR by recognizing the intrinsic links between humans, animals, and the environment(41,42). This approach emphasizes multidisciplinary and multisectoral collaboration to enhance overall health and well-being through integrated efforts(42).

Key Components of the One Health Approach

Interconnectedness: It’s important to understand that human health is closely connected to the health of animals and the environment(42).

Multidisciplinary Collaboration: Addressing AMR requires the involvement of various sectors, including healthcare professionals, veterinarians, environmental scientists, and policymakers(40).

Integrated Surveillance: Establishing surveillance systems that monitor AMR across different sectors is essential for tracking the emergence and spread of resistant microbes(42).

Sustainable Practices: Promoting practices that protect ecosystems and preserve the effectiveness of antimicrobial agents for current and future generations is vital5(40).

Impact of AMR on Different Sectors

Human Health: AMR can lead to infections that are harder to treat, resulting in increased morbidity, mortality, and healthcare costs. Infections like gonorrhoea and cystitis are becoming more difficult to cure, and routine surgeries carry higher risks.

Animal Health: The spread of resistant bacteria in animals can increase animal suffering and losses, affecting the livelihoods of people who depend on livestock(43).

Environmental Health: Antimicrobial pollutants in the environment can negatively impact biodiversity and ecosystems, further contributing to the spread of AMR(44). Resistant bacteria from treated animals can be present in manure and disseminate into the environment and wildlife(43).

Aspects responsible for spread of AMR

The dissemination of AMR is influenced by a range of factors, including:

Antimicrobial Use: Abuse and misapplication of antimicrobials in human, animal, and environmental sectors(45).

Socioeconomic Factors: World trade, conflict, displacement, and travel.

Local Factors: Contaminated habitats(42).

- Poor sanitation and pollution.
- Agricultural practices, particularly in food animal production(46).

The Role of the Environment in AMR

The environment serves as both a reservoir and a vehicle for spreading AMR

Environmental Contamination: Antibiotics and drug-resistant bacteria can reach the environment through sources like sewage, animal waste, and waste water.

Wildlife as Vectors: Wildlife, especially birds, can act as vectors for AMR transmission across the environment, spreading resistant bacteria through exposure to sewage and feces(46).

Impact on Ecosystems: Antimicrobial pollutants can alter soil biota and contaminate waterways, affecting biodiversity and potentially entering the food chain(44).

Strategies for Combating AMR

Combating AMR requires a multifaceted approach that includes:

Antimicrobial Stewardship: Implementing responsible antimicrobial use practices in human and animal healthcare to reduce unnecessary use(40).

Preventive Healthcare action: Enhancing hygiene and sanitation practices to prevent the spread of infections.

Surveillance and Monitoring: Establishing integrated surveillance systems to track AMR trends and identify emerging threats(42).

Research and Development: Investing in research to develop new antimicrobials, diagnostics, and alternative therapies.

Policy and Regulation: Implementing policies and regulations to promote responsible antimicrobial use and prevent environmental contamination(40).

Public Awareness and Education: Raising awareness among healthcare professionals, animal handlers, and the public about the importance of responsible antimicrobial use and hygiene practices(42).

Collective Efforts and Initiatives

Various organizations and initiatives are working to combat AMR through collective efforts:

FAO-OIE-WHO Alliance: A collaboration between the Food and Agriculture Organization (FAO), the World Organisation for Animal Health (OIE), and the World Health Organization (WHO) to mitigate the global threat of AMR by fostering integrated surveillance systems and control measures.

Global Antibiotic Resistance Partnership (GARP): An initiative that promotes evidence-based strategies for combating antibiotic resistance.

Global AMR Hub: An organization that facilitates collaboration and knowledge sharing among researchers, policymakers, and other stakeholders involved in AMR(42).

CONCLUSION:

Antimicrobial resistance (AMR) is a critical global public health threat that undermines the effectiveness of treatments for a wide range of infections(3). Approximately 5 million deaths are associated with bacterial AMR, highlighting the urgency of addressing this issue(47).

Key Findings on Antimicrobial Resistance

Global Impact: AMR is a leading cause of death worldwide, with over one million people dying each year because bacteria have become resistant to treatment(48). Between 2025 and 2050, an estimated 39 million people are expected to die from AMR(47,48).

Trends Over Time: From 1990 to 2021, AMR deaths among children under five decreased by 50%, while those among people aged 70 and older increased by over 80%(49). These trends are projected to continue, with deaths among older adults increasing while those among young children decrease(49).

Rising Resistance: There is increasing resistance to critically important antimicrobials. Resistance to carbapenems between Gram-negative bacteria has escalate rapidly(49).

Impact of the COVID-19 Pandemic: The COVID-19 pandemic has exacerbated the problem of AMR, leading to more resistant infections, increased antibiotic use, and reduced prevention efforts(50).

Geographic Disparities: Sub-Saharan Africa and South Asia are disproportionately affected by AMR1. Enhance healthcare availability and antibiotic availability could save millions of lives in these areas(48,49).

Potential for Prevention: Improved access to healthcare and antibiotics could save 92 million lives between 2025 and 2050. Developing new antibiotics targeting Gram-negative bacteria could avert 11.08 million AMR-attributable deaths over the same period(49).

The Urgent Need to Address AMR

The rise in AMR threatens the ability to treat common infections effectively(1). The 2022 Global Antimicrobial Resistance and Use Surveillance System (GLASS) report indicates alarming resistance rates among prevalent bacterial pathogens, such as *E. coli* and *Staphylococcus aureus*. Increased resistance can lead to greater use of last-resort drugs like carbapenems, which in turn are also showing resistance across multiple regions. The Organization for Economic Cooperation and Development (OECD) projects a twofold surge in resistance to last-resort antibiotics by 2035, compared to 2005 levels, underscoring the urgency for robust antimicrobial stewardship practices and enhanced surveillance(3). Without decisive action, antibiotic-resistant infections could be involved in approximately 8 million deaths each year by 2050, either as a direct cause or a contributing factor(49).

Future Research Directions

Future research is essential to combat AMR effectively. Key areas of focus include:

Novel Diagnostics: Developing new diagnostic tests to facilitate rapid and accurate identification of microbial infections. Molecular diagnostics, such as amplification technology with DNA microarrays, can boost accuracy of diagnosis and enable more careful antimicrobial drug use(51).

Therapeutics: Research is needed to develop new antimicrobial agents and alternative therapies to combat resistant infections(49).

Prevention Strategies: Modern vaccinology, including the development of new vaccines, can contribute to decreasing the transmission and impact of antimicrobial-resistant bacteria. Vaccines have the potential to control infectious agents by blocking their ability to spread within a population(51).

Multidisciplinary, Collaborative, and Regulatory Approach

Combating AMR requires a multidisciplinary approach involving collaboration among various sectors and the implementation of effective regulations.

Collaboration: Effective strategies necessitate a cooperative approach involving policymakers, healthcare professionals, researchers, and the public.

Regulation: Implementing policies and regulations to promote responsible antimicrobial use and prevent environmental contamination is crucial(51).

Vaccination: Vaccination programs can reduce the need for antibiotics, thereby decreasing the selective pressure that drives AMR.

Infection Control: Strengthening infection prevention and control measures in healthcare settings can limit the spread of resistant organisms(49).

Call to Action

Addressing AMR requires a concerted effort from policymakers, healthcare professionals, researchers, and the public. We must use antibiotics wisely, improve tracking systems, and support the discovery of new tests, treatments, and ways to prevent infections(51). Working together can help reduce the threat of antimicrobial resistance and keep antibiotics effective for future use.

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