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Combatting Antimicrobial Resistance: The Critical Role of Healthcare Providers in Prevention and Management

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Abstract:

Antimicrobial Resistance (AMR) has emerged as a critical global health challenge, threatening effective treatment of infectious diseases. Driven by overuse, misuse, and lack of regulation in both human and veterinary medicine, AMR results in increased mortality, prolonged illness, and significant economic impacts. Efforts to combat AMR focus on antimicrobial stewardship (AMS), involving rational prescription practices, diagnostics, and hospital hygiene protocols. The World Health Assembly's Global Action Plan (GAP) outlines five strategic priorities, including raising awareness, improving research, enhancing sanitation, optimizing antimicrobial use, and fostering sustainable investment in new treatments. International collaboration among governments, agencies, and organizations is key to addressing AMR through surveillance, improved diagnostics, and regulatory frameworks. The One Health approach underlines the interconnectedness of human, animal, and environmental health in AMR mitigation. Vaccines reduce antimicrobial demand by preventing infections, and community engagement fosters behavioral changes to reduce AMR. However, barriers to AMS implementation include resource limitations, lack of training, and regulatory gaps. By addressing these challenges and promoting collaborative efforts, AMS programs can enhance patient outcomes, reduce resistance, and support long-term public health sustainability.

Keywords: *Antimicrobial Resistance (AMR), Antimicrobial Stewardship (AMS), Global Action Plan (GAP), One Health, Vaccines, Diagnostics, Community Engagement, Public Health*

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Chapter 1: Introduction to Antimicrobial Resistance (AMR)

Antibiotics stand among the pivotal medical advancements of the 20th century, responsible for saving countless lives from infectious diseases. They have earned the moniker "magic bullets" for their ability to target and combat bacteria, marking them as one of medicine's most extraordinary breakthroughs (Mzumara et al., 2021). The advent of antibiotics redefined therapeutic practices and continues to protect millions from bacterial infections. These drugs have been a blessing for humanity, extending their utility beyond medicine into fields like animal husbandry and agriculture, where they are often used as preventative tools, especially in underdeveloped and developing regions (Salam et al., 2023).

Microorganisms, however, have evolved to develop antimicrobial resistance (AMR) due to the increased and often improper use of antibiotics, which creates high selection pressure. Resistance is characterized by a microbe's ability to adapt and survive despite exposure to antimicrobials. This adaptability is facilitated by resistance genes on mobile genetic elements such as plasmids, transposons, and integrons, which spread through horizontal or vertical gene transfer (Uddin et al., 2021). Antimicrobials, including antibiotics, antivirals, antifungals, and antiparasitics, are critical in treating infections across humans, animals, and plants (Ali & Mishra,).

AMR arises when bacteria, viruses, fungi, and parasites no longer respond to medications designed to eliminate them. Drug resistance renders antibiotics and other antimicrobials ineffective, making infections increasingly challenging to treat and thereby heightening the risks of disease spread, severe illness, disability, and mortality (Tang et al., 2023). While AMR occurs naturally through genetic changes over time, human activities—primarily the misuse and overuse of these drugs in treating and preventing infections—have expedited this process (Ahmed et al.,).

Antimicrobial resistance enables microorganisms like bacteria, viruses, fungi, and parasites to endure and thrive in the presence of drugs meant to eradicate them. Infections caused by resistant organisms not only become harder to treat but also pose increased risks of severe illness and mortality (Salam et al., 2023). AMR is an inevitable evolutionary response, driven by genetic mutations that help organisms resist the adverse effects of antimicrobial agents. To survive environmental selection pressure, bacteria develop mechanisms to counter antibacterial drugs, ultimately rendering these drugs ineffective (Solanki & Das,).

The extensive use of antibiotics, particularly in developing nations, provides bacteria ample opportunity to evolve resistance, leading to significant health impacts, including elevated morbidity and mortality (Muteeb et al., 2023). The incidence and prevalence of AMR bacterial infections have reached critical levels in the 21st century, representing a global public health threat described as a "silent pandemic" that urgently demands action. Antibiotic resistance affects people of all ages and can occur in any nation, posing not only a threat to global health but also to food security (Murray et al., 2022).

The rise in antimicrobial-resistant bacteria has become a worldwide concern, posing severe health risks and requiring immediate intervention (Ahmad et al., 2021). Therapeutic options for treating infections caused by resistant bacteria are limited, often resulting in higher rates of morbidity, mortality, and significant financial burdens. The demand for new antimicrobial agents to combat life-threatening resistant infections far outpaces the current supply, with few new discoveries (Tarín-Pelló et al., 2022).

The consequences of antibiotic resistance are profound for both treatment and prevention. Therapeutically, resistance leads directly to treatment failures and complications, while preventively, it limits options for vulnerable patients requiring immunosuppressive treatments, advanced surgeries, or invasive procedures (Huemer et al., 2020). Despite growing demand, the development of new synthetic and natural antimicrobials to address life-threatening resistant infections has not kept pace (Kumar et al., 2020).

The modern antibiotic era began with Paul Ehrlich's discovery of salvarsan and neosalvarsan in 1910 to treat syphilis caused by *Treponema pallidum* (Ferraz,). Later, Gerhard Domagk's discovery of prontosil, a sulfonamide, succeeded salvarsan. In the 1930s, Selman Waksman pioneered research on soil microbes' potential for producing antimicrobial compounds, leading to the discovery of several antibiotics, including streptomycin, a treatment for tuberculosis. Waksman defined an antibiotic as "a compound made by a microbe to destroy other microbes" (Hussain & Baqar, 2023).

Penicillin, discovered from the mold *Penicillium rubens* by Sir Alexander Fleming in 1928, initiated the "golden era" of antibiotic discovery, which reached its peak by the mid-1950s. The period between the 1940s and 1960s, often called the "Golden Age" of antibiotic discovery, yielded most of the antibiotics still widely used today (Iskandar et al., 2022). However, following this era, the rate of new antibiotic discoveries declined while drug-resistant pathogens continued to evolve. Antibiotic resistance was recognized nearly as early as antibiotics themselves, with penicillin-resistant *Staphylococcus* strains identified even before penicillin became a therapeutic agent in 1940 (Mestrovic et al., 2022).

In 1959, methicillin was introduced as the first semisynthetic penicillinase-resistant antibiotic, but methicillin-resistant *Staphylococcus* strains emerged as early as 1960, only a year after its release (Jiang et al., 2023). The glycopeptide antibiotic vancomycin was introduced in 1958 as a last-resort treatment for methicillin-resistant *Staphylococci* infections. However, vancomycin-resistant strains of coagulase-negative *Staphylococci* were reported by 1979, and vancomycin-resistant *Enterococcus* followed a decade later. By 1997, decreased efficacy of vancomycin for treating *Staphylococcus aureus* infections was observed, with reports of vancomycin-intermediate and vancomycin-resistant *Staphylococcus aureus* emerging in 1997 and 2002, respectively (Nassar et al., 2022).

The β-lactam antibiotic cephalosporin was discovered in 1945 and introduced in clinical settings in 1964 to treat penicillin-resistant infections. Since then, several generations of cephalosporins have been developed, with the fifth generation currently in use. Cephalosporins initially demonstrated high efficacy, particularly against extended-spectrum beta-lactamase (ESBL) producing gram-negative bacteria; however, significant resistance has developed across the first four generations (Suay-García & Pérez-Gracia, 2021). Another important antibiotic, tetracycline, discovered in 1950, was widely used for various common infections, including gastrointestinal diseases. Yet, within a decade of its introduction, resistance to tetracycline was reported in *Shigella* strains by 1959 (Kounatidis et al.,).

Levofloxacin, a third-generation fluoroquinolone, was added to the antibiotic arsenal in 1996, though resistance in *Pneumococcus* was reported the same year (LaPlante et al., 2022). Carbapenem, another β-lactam antibiotic introduced in 1980, was reserved for treating infections caused by cephalosporin-resistant enterobacteria. However, carbapenem-resistant enterobacterales (CRE) were reported globally from 2006, reflecting increased usage during the 1990s and 2000s (Hansen, 2021). The timeline of antibiotic discovery shows that pharmaceutical industries primarily introduced new classes of antibiotics between 1960 and 1980. After this period, the pace of new antibiotic discoveries slowed significantly until recent years (Szollosi, 2023).

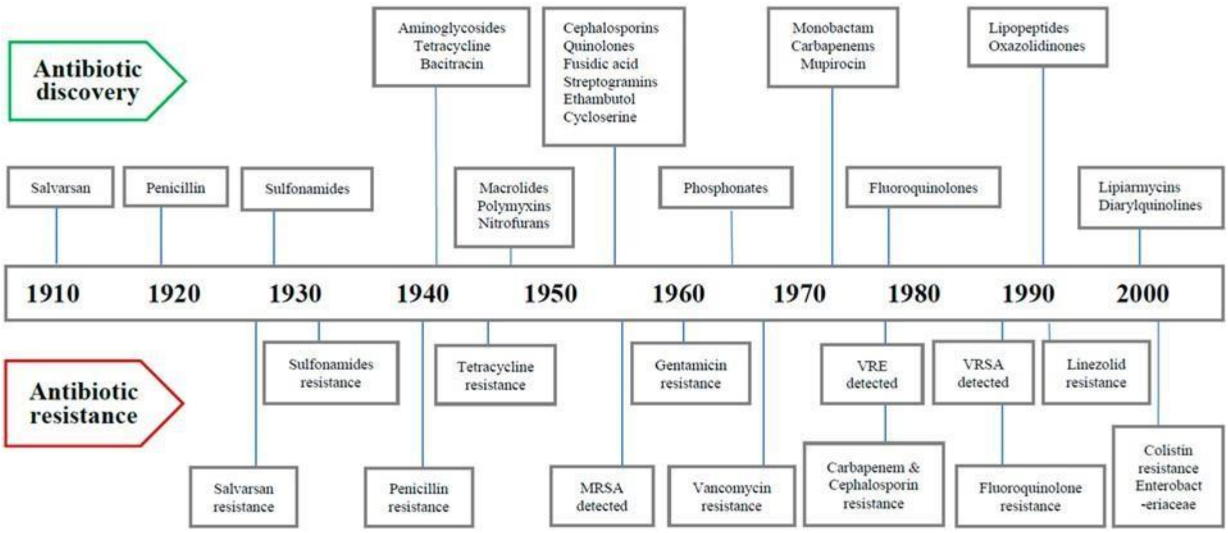

Figure 1. Timeline of discovery of major antibiotics and antibiotic resistance

Salam, M. A., Al-Amin, M. Y., Salam, M. T., Pawar, J. S., Akhter, N., Rabaan, A. A., & Alqumber, M. A. (2023, July). Antimicrobial resistance: a growing serious threat for global public health. In Healthcare (Vol. 11, No. 13, p. 1946). MDPI.

Diagnostics are essential in the fight against Antimicrobial Resistance (AMR), enabling the identification of specific pathogens responsible for infections and determining their resistance profiles. This information is crucial for clinicians to select the most effective treatments, improving patient outcomes and helping to control the spread of AMR (Kaprou et al., 2021). The emergence of novel resistance mechanisms, the rise of multi-drug resistance, and the ease with which resistance-encoding genetic material can sometimes spread horizontally across bacterial species all contribute to a growing sense of vulnerability in combating diseases once thought manageable with antibiotics (Elbehiry et al., 2022).

Chapter 2: The Scope and Drivers of AMR

The overuse and misuse of antimicrobials, especially antibiotics, are major contributors to the current AMR crisis, significantly increasing the global burden of antimicrobial resistance (Kakkar et al., 2020). With the rapid global spread of "superbugs"—microorganisms resistant to most antimicrobials—the threat of drug-resistant pathogens has reached critical levels. The World Health Organization (WHO) ranks AMR among the top three global public health threats, and antimicrobial-resistant infections are now the third leading cause of death, following cardiovascular diseases (Harun et al., 2022).

In 2019, AMR was directly responsible for approximately 1.3 million deaths. If unchecked, AMR could cause up to 10 million deaths annually by 2050, with as many as 90% of these fatalities occurring in low- and middle-income countries (LMICs) (Mestrovic et al., 2022). Beyond the health impacts, AMR imposes substantial financial burdens, affecting both individuals and society. Projections by the World Bank indicate that AMR could reduce global GDP by 1.1–3.8% by 2050, necessitating an annual investment of approximately $9 billion to counteract its effects. The highest death tolls from AMR are expected in Asia, followed by Africa, largely due to high population densities and a lack of regulatory measures (Pokharel et al., 2019).

In terms of mortality, sub-Saharan Africa has the highest all-age death rate associated with AMR, while Australasia had the lowest rate in 2019 (Naghavi et al.,). A prime example of a "superbug" is methicillin-resistant *Staphylococcus aureus* (MRSA), which continues to contribute to high mortality rates worldwide. Currently, 3.5% of active tuberculosis (TB) cases and 18% of previously treated TB cases are classified as multidrug-resistant TB (MDR-TB), with the rise of extensively drug-resistant TB (XDR-TB) posing increasing concern (Li et al., 2022).

The drivers of AMR are diverse, encompassing microbial characteristics and environmental factors involving both healthcare providers and consumers (Irfan et al., 2022). Contributing factors are broadly categorized into environmental (e.g., overcrowding, mass travel, inadequate sanitation, ineffective infection control, and agricultural antibiotic use), drug-related (e.g., counterfeit drugs, substandard quality, and over-the-counter access), patient-related (e.g., poor adherence to treatment, poverty, limited education, self-medication), and physician-related (e.g., inappropriate prescribing, inadequate dosing, and outdated training) (Saha & Sarkar, 2021).

Although antibiotic resistance is a natural phenomenon, it has been accelerated by the misuse of antibiotics in humans and animals. Overuse is strongly linked to the development of microbial resistance, despite repeated warnings from health organizations. Unfortunately, antibiotic misuse continues at alarming rates, with some experts fearing it may be too late to reverse current trends (Serwecińska, 2020).

A lack of antibiotic policy and standardized treatment guidelines exacerbates antibiotic misuse, especially in developing countries. Over-prescription by healthcare providers, pharmacies, and veterinarians, along with the availability of poor-quality antibiotics, has worsened the AMR situation (Nathwani et al., 2019). Unethical prescribing practices, motivated by financial incentives from pharmaceutical companies or to meet patient expectations, are also observed, particularly in developing countries (Malik et al., 2020).

Increased GDP growth, particularly in developing countries, has driven higher antibiotic consumption, correlating with improved quality of life in LMICs (Kenyon & Manoharan-Basil, 2020). Rising GDP is also associated with greater consumption of animal protein, which has contributed to the spread of AMR through animal sources (Chandra et al., 2021).

Inappropriate antibiotic prescribing remains a major factor in promoting AMR, with antibiotics often prescribed unnecessarily or with incorrect doses and durations. Ideally, antibiotic use should be guided by isolation of pathogens and susceptibility testing (Otaigbe & Elikwu, 2023). Meanwhile, the looming challenge of antibiotic resistance demands new drugs from pharmaceutical companies. Unfortunately, development has lagged; of the 51 newly developed antibiotics, only 8 are truly innovative against resistant bacteria, with most being reformulations of existing drugs (Stephens et al., 2020). The lack of novel options endangers the management of drug-resistant TB, urinary tract infections, pneumonia, and other gram-negative infections, particularly affecting vulnerable age groups (Sihombing et al., 2023).

Regulatory barriers and economic pressures hinder new antibiotic production, prompting many pharmaceutical companies to reduce investment in antibiotics research or withdraw entirely, favoring the development of drugs for chronic rather than infectious diseases (Mudenda et al.,).

Agricultural antibiotic use has risen significantly in developing countries to meet increased protein demand. The presence of antibiotic residues in animal-derived products (e.g., meat, milk, and eggs) contributes to AMR. Antibiotics are often used indiscriminately for animal disease treatment, feed preparation, and growth promotion, especially in countries with minimal regulatory oversight (Murugaiyan et al., 2022).

Global travel routes facilitate the spread of AMR as human movement helps transport resistant bacteria across borders. Travelers can return home carrying antimicrobial-resistant organisms, which may persist in the body for up to 12 months, amplifying transmission risks among vulnerable populations (Palma et al., 2020).

Significant knowledge gaps exist among healthcare workers (HCWs) and the general public regarding appropriate antibiotic use and resistance mechanisms. Surveillance data, essential for estimating AMR's impact and designing interventions like antimicrobial stewardship, remain limited worldwide (Kasimanickam et al., 2021). Addressing this knowledge gap through international collaboration among agencies, the healthcare sector, and agriculture is necessary for effective intervention (Nardulli et al., 2023).

Chapter 3: The Role of Healthcare Providers in AMR Prevention

Healthcare providers play a critical role in preventing AMR through the rational use of antimicrobials, controlling over-the-counter (OTC) antibiotic access, promoting hand hygiene, infection control, and fostering innovation in drug and vaccine development (Kasimanickam et al., 2021). Curbing the common practice of prescribing broad-spectrum antibiotics for minor conditions and monitoring veterinary antimicrobial use are also essential. Strategies to combat AMR include rational antibiotic prescriptions, limited prophylactic use, patient education, adherence to antibiotic regimens, and stringent hospital hygiene protocols under antimicrobial stewardship programs (Majumder et al., 2020).

Advancements in faster diagnostic tools and precise antimicrobial profiling are also vital for targeted therapy. According to WHO, "rational use of medicine" means using appropriate medications, including antibiotics, that meet patients' clinical needs in accurate doses, for the required period, and at minimal cost (Tomczyk et al., 2021). Optimal infection treatment requires minimizing drug toxicity, resistance development, and pathogen selection, achievable through rational antibiotic use. Antibiotic stewardship programs (ASPs) support this objective in healthcare settings (Sartelli et al., 2020).

Strict regulatory controls are necessary to ban OTC antibiotics, as OTC sales are still common in many developing regions (Maillard et al., 2020). Dispensing antibiotics only on physician prescriptions, coupled with continuous awareness campaigns about AMR for patients and dispensers, can mitigate misuse. Reviewing antibiotic policies based on local and regional AMR surveillance data is also recommended (Lynch et al.,).

Physicians, beyond direct patient care, play a vital role in adhering to infection control and antibiotic policies, reporting resistant cases, and preventing infection sources that could fuel AMR (Belcheva et al., 2022). Nurses and healthcare providers, frequently in close contact with patients, are integral to infection control and AMR prevention. Educating them about AMR and aseptic techniques helps reduce infection spread. Initiatives, such as master's programs in infection control nursing, enhance their role in AMR prevention (Kilpatrick et al., 2023).

Pharmacist-led ASPs are effective in improving antibiotic use, with pharmacists counseling patients with viral infections on the ineffectiveness of antibiotics and offering suitable OTC alternatives for symptom relief (Belcheva et al., 2022). Pharmacists also encourage referrals to physicians for suspected bacterial infections and educate patients on proper antibiotic use and treatment adherence, reducing unnecessary antibiotic consumption (Monmaturapoj et al., 2021).

Infection prevention and control (IPC) measures protect both patients and healthcare workers from preventable infections, including drug-resistant strains, and are crucial to reducing AMR in healthcare settings (Rout & Brysiewicz, 2020). Physicians, nurses, pharmacists, and other healthcare workers are essential in implementing IPC. Physicians can help prevent AMR by complying with infection control policies and timely reporting resistant cases (Aika & Enato, 2022). Educating healthcare providers about AMR and aseptic practices enhances infection control. Hospital pharmacists, as key IPC team members, encourage treatment adherence and proper antimicrobial use, supporting AMR prevention (Gilbert & Kerridge, 2020).

Recommended IPC measures in healthcare facilities include establishing an "infection prevention and control committee," practicing proper hand hygiene, ensuring accurate infection diagnoses and treatments, using antimicrobials responsibly, conducting continuous surveillance of antibiotic use and resistance, ensuring a reliable antimicrobial supply chain, and maintaining high-quality microbiological lab practices (Reddy et al., 2023).

Chapter 4: Antimicrobial Stewardship (AMS) Programs

The primary drivers of AMR include the lack of standardized antibiotic prescribing guidelines, irrational antibiotic use, financial incentives for prescribers, easy accessibility to OTC antibiotics, self-medication, patient demand, inadequate sanitation, insufficient infection prevention and control (IPC) practices, and the absence of antimicrobial stewardship programs (ASPs) (Al-Omari et al., 2020). In 2015, the World Health Organization (WHO) introduced a Global Action Plan (GAP) identifying ASPs as a key component to curb inappropriate antibiotic use. Antibiotic stewardship promotes the responsible use of antimicrobials through coordinated, evidence-based, multidisciplinary interventions to combat AMR (Otieno et al., 2022).

Antimicrobial stewardship (AMS) is defined as a continuous effort by healthcare organizations to optimize antimicrobial use, enhancing patient outcomes, reducing costs, and minimizing AMR-related consequences (Akpan et al., 2020). ASPs in hospitals, alongside IPC measures, are central strategies to combat AMR, improve clinical outcomes, and reduce costs by promoting the rational use of antibiotics. ASP interventions are adapted to fit each hospital's unique infrastructure (Chetty et al., 2019).

The term "stewardship" implies the careful management of a valuable resource, a concept applicable to the judicious use of antimicrobials. AMS programs aim to influence prescriber behavior and promote new practices, which requires understanding behavior change theories to effectively guide AMS efforts (Nathwani et al., 2019). AMS encompasses strategies that optimize antimicrobial therapy to improve patient outcomes and minimize AMR by limiting drug toxicity and reducing costs without compromising quality and safety (Hegewisch-Taylor et al., 2020). Stewardship interventions can be categorized as persuasive (education and feedback), structural (new diagnostic tests), enabling (guidelines for antibiotic use), or restrictive (requiring expert approval for certain antibiotics) (Weier et al., 2021).

AMS programs employ strategies to reduce unnecessary antimicrobial use and promote agents less likely to foster resistance, aligning with treatment guidelines and local resistance patterns (Avent et al., 2020). ASPs are pivotal to WHO's GAP to combat AMR, advocating rational antibiotic use for patient-centered outcomes (Pauwels et al., 2021). However, ASP research is largely confined to high-income settings with well-resourced hospitals, leaving gaps in understanding its implementation in low-resource environments (Ayton et al., 2022). The primary goal of AMS is to ensure the selection of appropriate antimicrobials, dosages, and durations to optimize treatment for each patient (Restrepo-Arbeláez et al., 2023). Other objectives include preventing antimicrobial misuse and minimizing resistance development through sustainable access to antibiotics for those in need (Cantón et al., 2023). The CDC's "Core Elements" of antimicrobial stewardship, released in 2014, provide implementation guidance adaptable to hospitals of all sizes (Rondon et al., 2023).

Effective AMS programs reduce inappropriate antimicrobial use, improve patient outcomes, and lower the incidence of resistance, toxicity, and unnecessary costs. Together with IPC, hand hygiene, and surveillance, AMS is essential in preventing AMR and reducing preventable infections, which are closely linked to inappropriate antimicrobial use (Sumon et al.,). Health organizations should refer to established guidelines when developing AMS programs, which should be tailored to fit the organization's size, complexity, and resources available for implementation, monitoring, and evaluation (Díaz-Madriz et al., 2023).

AMS promotes responsible antimicrobial use at individual, national, and global levels, encompassing human, animal, and environmental health (Fabre et al., 2022). These programs optimize antimicrobial use, improve outcomes, reduce AMR, and decrease healthcare-associated infections (HAIs) and costs. Effective ASPs demonstrate reductions in antimicrobial consumption, resistant infections, and hospital stays (Alghamdi et al., 2021). Successful ASPs typically include strong leadership, drug expertise, prescriber accountability, and targeted training. However, most evidence supporting ASPs comes from high-resource settings, limiting applicability to resource-limited environments (Wade et al., 2023).

AMS uses interventions such as structural changes (new diagnostic tools), persuasive strategies (behavior change in prescribing practices), enabling strategies (educational guidance), and restrictive controls (regulations on antimicrobial use) (Porto et al., 2022). Complementary measures include promoting clean water, hygiene, and infection prevention. AMS strategies rely on guidelines with quality indicators for each intervention, and WHO recommends AMR surveillance to identify resistance patterns and track interventions. Context-specific policies and protocols are needed to guide AMS solutions effectively, particularly in low-resource settings (Rivera et al., 2023).

Chapter 5: Policies and Guidelines

Decades of alarm have led to numerous calls to action, reports, guidelines, national action plans, and policy proposals. The emergence of multi-antibiotic-resistant bacteria turned bacterial resistance into a pressing global issue (Sarkar et al., 2023). One Health Approach, AMR is an emerging issue where a unified global approach is required. With all aspects considered, AMR emerged as one of the most prominent "*One Health*" issues, since AMR has the ability to spread rapidly across the population as well as in the food chain, healthcare settings and the environment, thereby making it more challenging to manage many infectious diseases in both humans and animals (Mudenda et al., 2023).

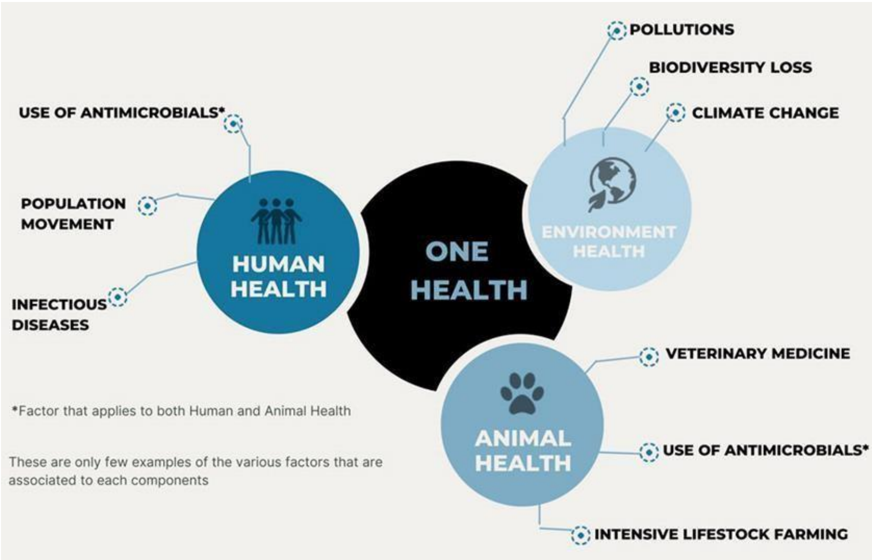

FIGURE 3. Illustration representing the concept of One Health Approach.

Tang, K. W. K., Millar, B. C., & Moore, J. E. (2023). Antimicrobial resistance (AMR). *British Journal of Biomedical Science*, *80*, 11387.

The "One Health" concept highlights the interconnectedness of human and animal health, advocating for guidelines on veterinary antimicrobial use to address AMR risks associated with these medications. This approach promotes awareness of AMR beyond human medicine, encouraging broader understanding of the issue (Cella et al., 2023). In line with this approach, the WHO launched the Global Action Plan on Antimicrobial Resistance (GAP-AMR) in 2015 to ensure that infectious diseases remain treatable by preserving antimicrobials through responsible use and accessibility standards. One key objective is to enhance antimicrobial use across human and animal health, requiring robust regulatory frameworks (Nastasijevic et al., 2023).

Prominent regulatory agencies, like the U.S. Food and Drug Administration (FDA) and Ireland's Health Products Regulatory Authority (HPRA), oversee antimicrobials for both human and animal use, while the UK uses separate bodies: the Medicines and Healthcare products Regulatory Agency (MHRA) for humans and the Veterinary Medicines Directorate (VMD) for animals (Mudenda et al.,). Another initiative, the Global Antimicrobial Resistance and Use Surveillance System (GLASS), focuses on global AMR surveillance to identify causes and provide remedial guidance for nations (Mishra et al.,).

The United Nations' Sustainable Development Goals (SDGs), particularly SDG3—"Good Health and Wellbeing"—include AMR-specific targets, such as indicator 3.d.2 on bloodstream infections from resistant organisms. WHO notes that AMR impacts seven of the 17 SDGs, affecting environmental, social, and economic goals (Scharlemann et al., 2020). Some global health experts argue for a legally binding global framework to standardize antimicrobial use, regulate antibiotic marketing, and strengthen global surveillance, drawing lessons from successful environmental agreements that employ sanctions for non-compliance, implementation assistance, independent scientific panels, and specific commitments (Weldon & Hoffman, 2021).

Policymakers play a crucial role in tackling AMR by strengthening tracking and lab capacity, regulating medicine use, and fostering innovation. Collaboration among governments, industry, and researchers remains vital for addressing AMR (Rogers Van Katwyk et al., 2023). In the U.S., the National Action Plan for Combating Antibiotic-Resistant Bacteria (CARB) 2023-2028 outlines strategies for reducing antibiotic resistance, promoting infection prevention, and advancing new antibiotic research. The plan also supports stewardship across healthcare, agriculture, and veterinary sectors (Yadav et al.,).

A proposed bill would introduce a subscription-based model to incentivize new antimicrobial development and support stewardship programs, addressing economic challenges in producing novel antimicrobials. However, quantifying the costs and benefits of AMR strategies is challenging, as policy effects may not materialize immediately (Umber & Moore, 2021). Mathematical modeling, often used in infectious disease management, could provide insights into AMR's development and policy impacts, although further research is needed to refine these models for AMR (Sanders et al., 2020).

Public awareness efforts can target broader audiences or specific stakeholders directly involved in antimicrobial use. Developing clear, prioritized messages on AMR may benefit from qualitative research and contextualized surveys to ensure effective communication (Majumder et al., 2020).

Chapter 6: Challenges in Combatting AMR

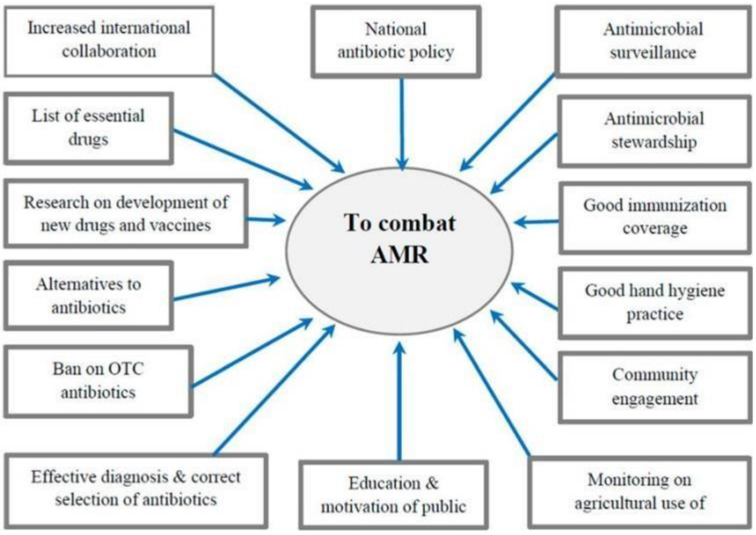

Figure 3. Major interventions to combat AMR.

Salam, M. A., Al-Amin, M. Y., Salam, M. T., Pawar, J. S., Akhter, N., Rabaan, A. A., & Alqumber, M. A. (2023, July). Antimicrobial resistance: a growing serious threat for global public health. In Healthcare (Vol. 11, No. 13, p. 1946). MDPI

To combat AMR effectively, key strategies include rational antibiotic prescribing, limiting prophylactic antibiotic use, educating patients, promoting adherence to antibiotic regimens, and enhancing hospital hygiene through antimicrobial stewardship (Ferrara et al.,). Developing faster diagnostic tools and accurate antimicrobial profiling for targeted therapy is equally essential. The World Health Assembly's five strategic action plans to combat AMR focus on: raising awareness, strengthening surveillance and research, implementing effective sanitation and hygiene practices, optimizing antimicrobial use in human and animal health, and fostering sustainable investment in new medications, diagnostic tools, and vaccines (Chindelevitch et al., 2022).

Internationally, collaborative efforts among agencies, governments, NGOs, and professional groups can enhance surveillance networks, improve lab capacity to detect AMR pathogens, and establish tracking systems for emerging threats. Global measures should also address counterfeit antimicrobial controls and invest in research for new drugs and vaccines (Mudenda et al., 2023; Aijaz et al., 2023). Nationally, countries can implement antibiotic policies in healthcare and agriculture, strengthen surveillance, develop point-of-care diagnostics, and promote research on new antibiotics. National stewardship programs, including essential drug lists, are critical to these efforts (Willemsen et al., 2022).

Vaccines play a crucial role in reducing AMR by preventing infections, thereby lowering the need for antibiotics and slowing the spread of resistant pathogens. Vaccines usually do not induce resistance in pathogens because they attack pathogens in diverse ways. Increased vaccine use correlates with reduced antibiotic-resistant strains and lower antibiotic demand (Nabadda et al., 2021; da Silva Jr et al., 2020). According to a WHO report, vaccines targeting 24 pathogens could cut global antibiotic demand by 22% or 2.5 billion daily doses annually, significantly reducing AMR-associated hospital costs (Rampedi et al.,).

Community engagement is essential, as AMR development often relates to daily practices in hygiene, food production, and healthcare behaviors. Since community perceptions and language around antimicrobials may vary, targeted community engagement can foster behavior change, safeguarding current and future treatment options (Munkholm & Rubin, 2020). Further research on community perspectives can translate into actionable strategies for combating AMR (Ogyu et al., 2020).

Addressing AMR also requires innovation in drug and technology development. Efforts from national, international, governmental, and academic sectors are needed to identify new antibiotic classes and diagnostic tools. Funding for antimicrobial research, especially for public health diseases, can advance drug development (Sayegh et al., 2021).

Challenges to implementing ASPs include human resource shortages, limited leadership, minimal government support, lack of laboratory infrastructure, and insufficient ASP training. Additional barriers are time constraints, inadequate funding, and absence of national guidelines (Fabre et al., 2023; Chang et al., 2022). Other obstacles include incomplete electronic medical records, long test wait times, overcrowding, staff turnover, and limited ASP goals (Verma et al., 2019).

Facilitators for ASPs include WHO-based antibiotic guidelines, multidisciplinary ASP committees, access to microbiology labs with antibiograms, electronic health records, and restricted antimicrobial lists in hospitals. Antibiograms, summarizing antimicrobial susceptibilities of local bacterial isolates, help track resistance trends and guide local antibiotic use. Infection prevention guidelines, external audits, and pharmacist empowerment further support ASP success (Nassar et al., 2022; Atif et al., 2021).

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