CHAPTER 7

ANTIMICROBIAL RESISTANCE (AMR): CAUSES, CONSEQUENCES AND SOLUTIONS

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ABSTRACT:

A major global public health concern, antimicrobial resistance (AMR) has been closely linked to a number of variables, including the inappropriate and excessive use of antibiotics, the environment, and unsatisfactory infection control procedures. The expansion and range of AMR cause significant challenges for the effective treatment of infectious diseases, leading to increased morbidity, mortality, and economic burden. The emergence of the Fourth Industrial Revolution (Industry 4.0) has the budding to revolutionize the field of medicine, providing new tools and skills for the prevention and treatment of infectious diseases. However, the widespread adoption of Industry 4.0 technologies in healthcare also raises new challenges, particularly with respect to the potential impact on AMR. As such, it is essential that efforts to tackle AMR are integrated to the broader context of Industry 4.0, and that stakeholders across multiple sectors work together to develop and implement effective solutions to this global health threat. This chapter provides an overview of the key factors support to the growth and range of AMR, as well as the economic and environmental consequences of this problem. The chapter also outlines a range of strategies for promoting appropriate use of antibiotics, including public education and awareness campaigns, investment in research and development for new antibiotics and other treatments, and the need for international collaboration. Finally, the chapter emphasizes the causes, consequence and Solutions of AMR and the critical role of continued research and collaboration in addressing this global public health threat within the context of Industry 4.0.

7.1. INTRODUCTION:

The chapter on Antimicrobial Resistance (AMR) is of greatest importance in the context of the fourth Industrial Revolution (Industry 4.0). With the increased use of technology and automation in various industries, there is a corresponding increase in the usage of antibiotics and other antimicrobial agents. This has led to the expansion and spread of AMR, which poses a serious threat to global public health. The chapter highlights the root cause, consequences, and solutions to tackle the AMR. It also emphasizes the need for international collaboration, public education, research and development to combat AMR. Therefore, the chapter helps as a pointer to the importance of responsible use of antibiotics and the urgent need to act against AMR in the context of Industry 4.0.

Antibiotics, antifungals, anti-protozoans, and anthelmintic have all been overused and misused, which has led to the development of antimicrobial resistance (AMR), a serious public health issue. Any substance that has the power to eradicate or prevent the development of germs is referred to as "antimicrobial."

7.1.1 WHAT ARE MICROBES?

Small, living things called microbes can only be seen under a microscope. They consist of bacterial, viral, fungal, protozoal, and algal species. These microorganisms are found in all parts of the world and play important roles in many aspects of our lives.

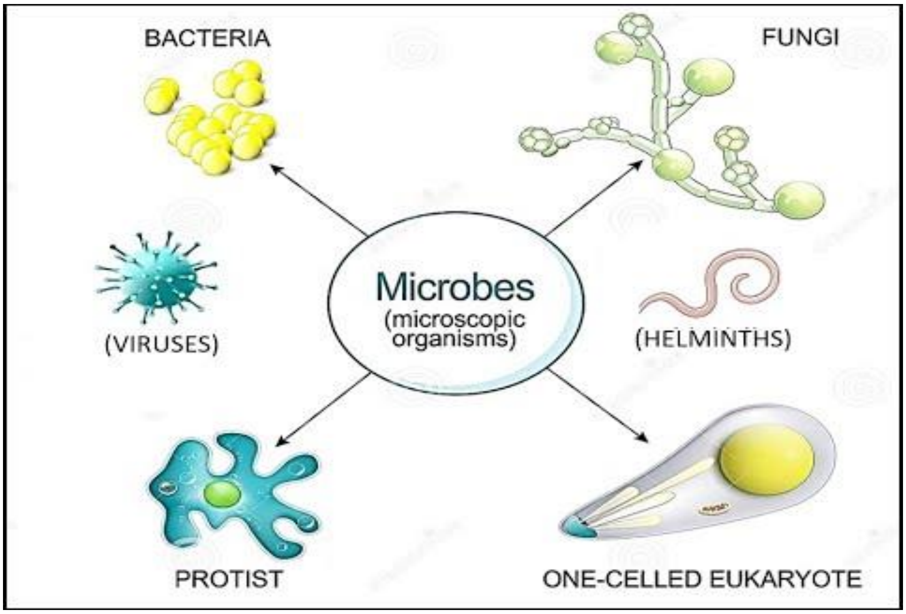

FIGURE 7.1: MICROSCOPIC ORGANISMS

For example, they are involved in food production, the recycling of nutrients, the breakdown of waste products, and the maintenance of healthy ecosystems. Some microbes are also used in the production of medicines and other useful products. However, some microbes can also cause disease, and the ability of these microorganisms to grow resistance to antimicrobial drugs is a growing concern.

7.1.2 THE SIGNIFICANCE OF AMR

The problem of AMR is not new. The first cases of AMR were reported shortly after the discovery of penicillin in 1928, and since then, the problem has only worsened. Antibiotic misuse and overuse has resulted in the emergence of resistant bacterial strains, which make infections harder to cure and raise the risk of morbidity and mortality. According to the World Health Organisation (WHO), AMR is one of the top 10 global public health concerns to humanity at the present time.

AMR is significant because it has the potential to compromise the efficacy of contemporary medicine. Throughout the course of human history, infectious diseases have been a significant cause of morbidity and mortality. The discovery of antimicrobial medications has revolutionised the way these diseases are treated. The emergence of AMR, however, poses a threat to erase a lot of the advancements accomplished in this field. If AMR is not stopped, it could result in a day when even non-life-threatening infections can be fatal and common medical operations like chemotherapy and surgery are no longer safe to conduct.

7.1.3 IMPORTANCE OF UNDERSTANDING CAUSES OF AMR

This chapter discusses the complex and multifaceted origins of AMR, which include issues including antibiotic abuse and overuse, environmental propagation of resistant microbes, and genetic alterations. Perhaps the most important factors in the emergence of AMR are antibiotic overuse and abuse. Antibiotics are frequently administered without significant need and patients frequently do not finish the entire course of therapy which can foster the growth of bacterial strains that are resistant to them.

7.1.4 IMPORTANCE OF UNDERSTANDING CONSEQUENCES OF AMR

This chapter also deals with the various types of consequences of AMR which can be severe and far-reaching, affecting not only human health but also the economy and the environment. The consequences of AMR include increased morbidity and mortality rates, increased healthcare costs, economic consequences, and detrimental environmental consequences. The increased morbidity and mortality rates associated with AMR are of particular concern, as they represent a significant risk to community wellbeing. AMR can make toxicities which is more challenging to treat, leading to longer hospital stays, increased healthcare costs, and a greater risk of death.

The economic consequences of AMR are also significant. Treating infections initiated by resistant strains of microbes can be more expensive than handling toxicities caused by non-resistant strains, which can lead to increased healthcare costs for individuals, healthcare providers, and governments. The economic consequences of AMR can also extend beyond the healthcare sector, affecting industries such as agriculture, tourism, and transportation.

The environmental consequences of AMR are also a concern. Antibiotic use in waste management and agriculture may encourage the growth of environmentally contagious, resistant bacteria that can infect people and animals. Long-term effects on the ecosystem and public health may result from this.

7.1.5 SOLUTIONS FOR TACKLING ANTIMICROBIAL RESISTANCE (AMR).

This chapter illustrate that how we can solve the problem related with the AMR. For this it is necessitate a coordinated effort by the public, healthcare providers, pharmaceutical sector, and governments. To address AMR, it is crucial to encourage the proper use of antibiotics, decrease needless antibiotic usage in animal agriculture, engage in research and development, encourage international cooperation, and raise public knowledge of the problem.

Promoting appropriate use of antibiotics is perhaps the most important step that can be taken to combat AMR. This can be achieved by advocating the use of alternative treatments when appropriate, ensuring that antibiotics are only provided when necessary, and educating healthcare professionals and patients about the proper use of antibiotics.

Another crucial step in the fight against AMR is reducing the use of antibiotics in animal husbandry. Animal agriculture frequently uses antibiotics to boost growth and ward off disease, which can hasten the emergence of bacterial strains that are resistant to treatment.

Reduced use of antibiotics in animal agriculture can slow the growth of resistant bacteria and encourage the creation of substitute treatments and preventions for animal diseases.

The fight against AMR also requires significant investment in Research and Development. In addition to developing novel antibiotics, this also entails creating alternative therapies and diagnostic equipment that can lessen the need for antibiotics.

The pharmaceutical industry plays a critical role in this effort, but government funding for research and development is also necessary to ensure that new drugs and treatments are developed.

The battle against AMR also requires international cooperation. Governments, healthcare providers, and the general public must work together to find a solution to the global issue of AMR.

A Global Action Plan on AMR has been formed by the WHO with the intention of raising awareness of the issue, promoting the sensible use of antibiotics, and fostering the creation of novel medications and therapies. (Antibiotics, 2022)

Finally, public education and awareness are essential in the fight against AMR. The public shows a critical part in promoting the appropriate use of antibiotics, and educating the public about the risks associated with AMR can help to promote responsible antibiotic use. This may involve teaching people on the value of finishing an antibiotic course, refraining from using antibiotics for viral infections, and maintaining excellent cleanliness to stop the spread of diseases.

7.2. BACKGROUND AND DISCOVERY OF ANTIBIOTICS

The discovery of antibiotics is one of the most significant events in the history of medicine. Antibiotics are powerful drugs that can kill or inhibit the growth of bacteria, and they have revolutionized the treatment of many infectious diseases.

The use of antibiotics dates back to ancient times when people used mouldy bread or other substances to treat infections. However, the modern era of antibiotics began in the 1920s and 1930s, when researchers began to explore the antimicrobial properties of various substances.

One of the most significant discoveries in the development of antibiotics was made by **Alexander Fleming in 1928. Fleming** was a Scottish scientist employed at London's St. Mary's Hospital. When he discovered that a mould that had gotten into one of his petri dishes was preventing the growth of the bacteria, he was studying the characteristics of the Staphylococcus bacteria. (1943, Waksman and Schatz). The mould was discovered to be a strain of Penicillium, and he discovered that it was creating a chemical that was capable of killing certain germs. (Chain and et al, 1940).

Fleming named this substance penicillin, and he spent several years investigating its properties and potential uses. However, he was unable to develop a method for producing penicillin in large quantities, and his work was largely ignored by the medical community. (Fleming A., 1929).

It wasn't until the 1940s that a group of scientists led by **Howard Florey** and **Ernst Chain** succeeded in turning penicillin into a practical antibiotic. **Florey and Chain** were working at the University of Oxford and had access to a more sophisticated laboratory than **Fleming.**

They were able to develop methods for producing penicillin in large quantities, and they conducted clinical trials that showed the drug to be highly effective against a range of bacterial infections. (Finch and et al 1985).

The invention of penicillin cleared the path for the discovery of further antibiotics, and scientists started looking into the potential of other natural substances to either kill or stop the growth of bacteria. **Selman Waksman** and his team at **Rutgers University** discovered streptomycin, the first antibiotic effective against tuberculosis, in **1943**.

The following decades saw the development of Tetracycline, erythromycin, and vancomycin, among other significant antibiotics.

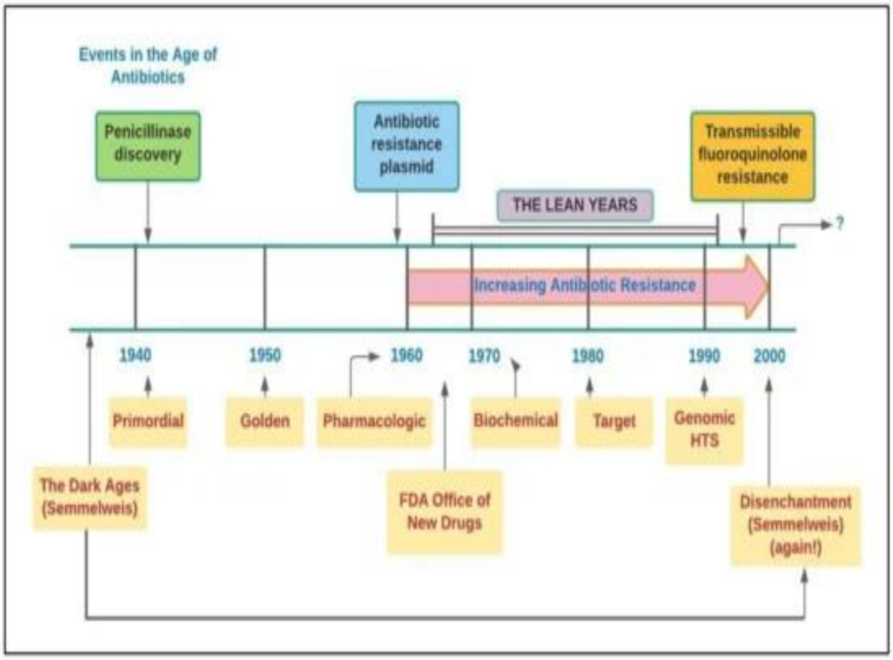

FIGURE 7.2: DISCOVERY AND PROGRESS OF ANTIBIOTICS

Antibiotics are one of the kinds of medications that are currently most frequently prescribed, and they are used to treat a variety of bacterial diseases. Antibiotic-resistant bacteria have however, emerged as a result of antibiotic overuse and misuse, which is a major public health concern. An important field of study continues to be the creation of fresh antibiotics and different forms of treatment for bacterial illnesses.

During his 1945 Nobel Prize lecture, Alexander Fleming issued a warning about the potential danger of resistance. He noted that it was not difficult to create penicillin-resistant microbes in the laboratory by exposing them to sub-lethal doses of the drug. He also cautioned that this phenomenon had been observed in the body, where exposure to non-lethal amounts of the drug could also lead to the development of resistance in microbes.

7.3. CAUSES OF ANTIMICROBIAL RESISTANCE

AMR stands for antimicrobial resistance, which is the capacity of microorganisms like bacteria, viruses, fungus, and parasites to withstand the effects of antimicrobial agents including antibiotics, antivirals, antifungals, and anti-parasitic. The resistance occurs when the microorganisms develop mechanisms to protect themselves from the antimicrobial agents or neutralize their effects. There are many causes of AMR from which some common causes are given in figure 3.0, like absence of proper surveillance system, excess use of antibiotics, inadequate infection control practices in Hospital, lack of awareness, insufficient financial resources, limitations of recent AMR data, inadequate diagnostic capacity, improper management of sanitation of waste and many more. (Laxminarayan *etal*, 2013).

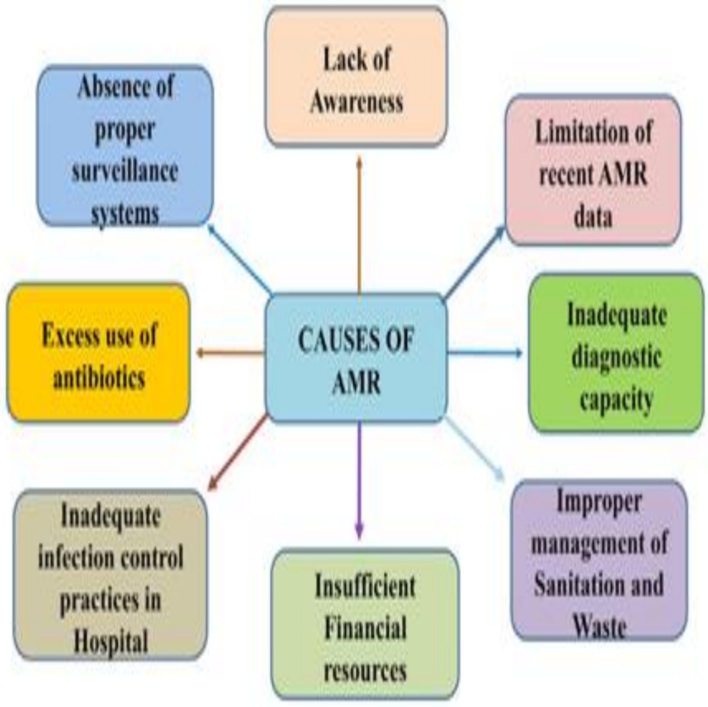

FIGURE 7.3: COMMON CAUSES OF AMR

AMR poses a severe threat to public health because it reduces the efficacy of antimicrobials, making it more challenging to treat diseases brought on by resistant germs. This can lead to increased morbidity, mortality, and healthcare costs, as well as the potential for the spread of resistant microorganisms to other individuals and populations. Therefore, it is essential to understand the causes and mechanisms of AMR to develop effective strategies for prevention and control.

Antimicrobial resistance (AMR) is primarily developed through the selective pressure that is exerted on bacteria in response to exposure to antimicrobial agents such as antibiotics, antivirals, and antifungals. When these agents are used to treat infections, they target and kill the bacteria causing the infection. However, they also expose the bacteria to a strong selective pressure, which favours the growth and proliferation of any bacteria that have developed resistance.

Resistance can develop through a variety of mechanisms, including mutation and acquisition of resistance genes. Mutations are changes in the genetic material of bacteria that can occur spontaneously, allowing them to survive in the presence of antibiotics. When bacteria absorb genetic material from other bacteria through processes including conjugation, transformation, and transduction, they often acquire resistance genes as a result.

Antimicrobial agent abuse and overuse are further factors in the growth of AMR. Frequent usage of antibiotics may foster conditions that encourage the emergence and spread of resistant microorganisms. Antibiotic misuse, such as using them to treat viral illnesses or overusing them for minor infections, also aids in the emergence of resistance.

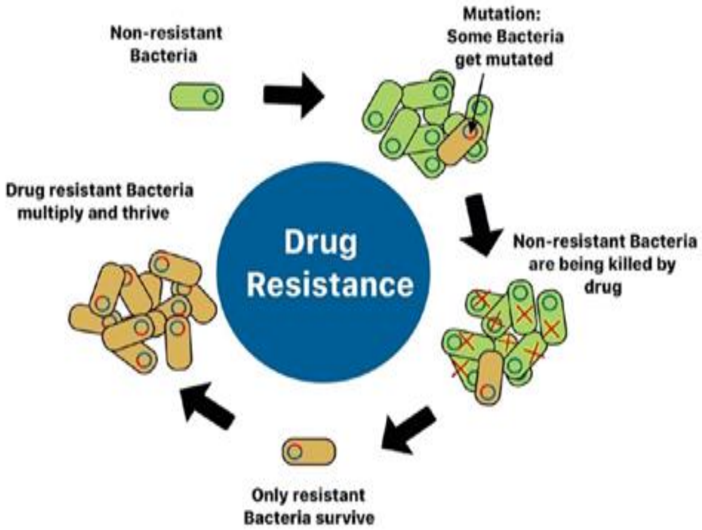

FIGURE 7.4: DEVELOPMENTAL MECHANISM OF AMR

The use of inappropriate antibiotic dosages is another element that may contribute to the emergence of resistance. When antibiotics are not administered at the right dosage or for the right duration of time, the infection-causing bacteria may not be entirely eradicated, which allows them to evolve resistance.

Overall, the expansion of AMR is a multifaceted process that involves a combination of selective pressure, genetic mechanisms, and the environment. Effective strategies for combating AMR must take into account these factors and focus on reducing the selective pressure on bacteria, promoting appropriate use of antimicrobial agents, and developing new antimicrobial agents with novel mechanisms of action.

7.3.1 FACTORS RELATED WITH AMR

Antimicrobial resistance (AMR) is a complicated problem that is influenced by a number of variables. The overuse and abuse of antibiotics by patients and prescribers is one of the main contributing reasons.

As a result, bacteria that are resistant to medication grow and have the potential to spread, resulting in infections that are challenging to cure. Environmental variables, including as exposure to antibiotics in food and water sources, can also contribute to the development of AMR in addition to these considerations.

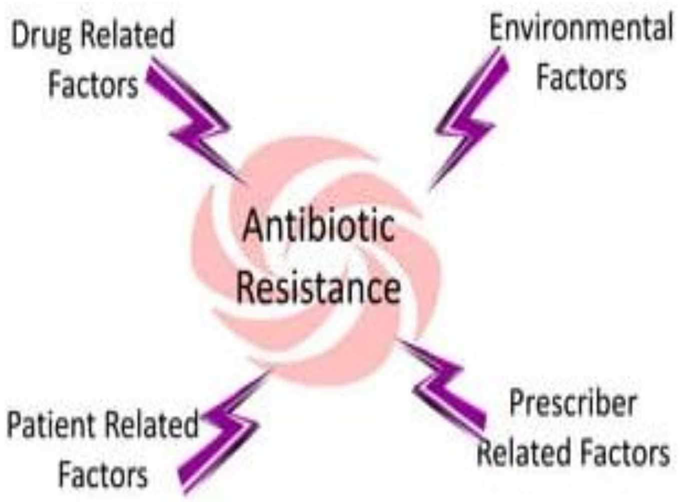

FIGURE 7.5: FACTORS OF ANTIBIOTIC RESISTANCE

All of these issues must be taken care of if we are to successfully tackle the growing threat of AMR and maintain the potency of our antibiotics.

7.3.1.1 OVERUSE AND MISUSE OF ANTIBIOTICS IN HUMAN MEDICINE:

Antibiotic resistance in bacteria can be brought about by overusing them or using them incorrectly, such as for viral illnesses.

This is due to the fact that the antibiotics only cause the bacteria to be exposed rather than destroyed, which allows the germs to develop drug resistance.

7.3.1.2 OVERUSE AND MISUSE OF ANTIBIOTICS IN ANIMAL AGRICULTURE:

Antibiotics are frequently added to animal feed to aid in growth and prevent diseases, however doing so, can cause animals to develop antibiotic-resistant in bacteria. Then, through direct touch or ingestion of tainted animal products, these resilient germs can spread to people.

7.3.1.3 POOR INFECTION CONTROL PRACTICES IN HEALTHCARE SETTINGS:

Inadequate hand hygiene, improper cleaning and sterilization of medical equipment, and the overuse of broad-spectrum antibiotics in hospitals can create an environment where resistant bacteria can thrive. This can lead to healthcare-associated infections that are difficult to treat.

7.3.1.4 LACK OF EFFECTIVE VACCINES AND DIAGNOSTIC TOOLS:

Without proper tools to diagnose and prevent infections, antibiotics may be overused, leading to resistance. In addition, lack of effective vaccines can also contribute to the overuse of antibiotics. Vaccines help to prevent infections against invading microbes and reducing need for antibiotics.

7.3.1.5 GLOBAL TRAVEL AND TRADE:

The rapid spread of resistant bacteria can occur through travel and trade, especially in areas with high antibiotic use and poor infection control. This can lead to the introduction of resistant bacteria into new areas, making it more difficult to control the spread of these organisms.

7.3.1.6 ENVIRONMENTAL FACTORS:

By releasing trash into the environment, hospitals, farms, and homes can release antibiotics. As a result, the environment may become residence for microbes that are resistant to antibiotics which can subsequently spread to people or other animals.

7.3.1.7 POOR PRESCRIBING PRACTICES BY HEALTHCARE PROVIDERS:

Due to unwanted prescription of antibiotics by healthcare providers may leading to overuse and resistance. This can occur due to patient pressure or lack of knowledge about appropriate antibiotic use.

7.3.1.8 LACK OF EDUCATION AND AWARENESS:

Patients may demand antibiotics even when they are not needed, or may not complete a full course of antibiotics as prescribed. In addition, healthcare providers may not be aware of the importance of appropriate antibiotic use or the risks associated with resistance.

7.3.1.9 OVERUSE OF ANTIBIOTICS IN THE FOOD INDUSTRY:

In order to encourage growth and avoid sickness in cattle, antibiotics are frequently employed in agriculture. This may result in the growth of bacteria resistant to antibiotics in animals, which may subsequently spread to people

7.3.1.10 LACK OF NEW ANTIBIOTICS IN DEVELOPMENT:

There are now fewer alternatives for treating resistant diseases because the production of new medicines has decreased recently. This may result in the overuse of already prescribed antibiotics which would increase resistance.

7.3.2 ROLE OF EXCESSIVE AND INAPPROPRIATE USE OF ANTIBIOTICS

Antimicrobial resistance (AMR) is a crucial factor in the emergence and spread due to the excessive and inappropriate use of antibiotics. Antibiotic-resistant bacteria are those that survive and proliferate in the presence of antibiotics, therefore overusing those results in their selection and spread. Both human and animal populations are susceptible to this. For instance, doctors may prescribe antibiotics for viral infections or for diseases like the common cold or flu that should not be prescribed due to wasteful use. Additionally, patients may not be taking all prescription antibiotics that may accelerate the emergence of antibiotic resistance.

Antibiotics are frequently used in agriculture to help livestock grow and avoid diseases, however this practise can result in the emergence of bacteria that are resistant to antibiotics. Then, by eating certain foods or coming into close touch with certain animals, these resistant bacteria can transfer to people.

AMR can potentially spread as a result of the usage of antibiotics in the environment, such as in wastewater treatment facilities or agricultural runoff. This is because resistant bacteria and drugs can be released into the environment and then spread to people or other animals.

In order to combat AMR, it is essential to reduce the excessive and improper use of antibiotics. This entails encouraging the proper use of antibiotics in both human and animal populations and putting policies in place to stop medicines from leaking into the environment.

7.3.3 IMPORTANCE OF ENVIRONMENTAL FACTORS IN THE DEVELOPMENT OF AMR

Environmental factors play a significant role in the development and spread of antimicrobial resistance (AMR). The release of antibiotics and resistant bacteria into the environment, either intentionally or unintentionally, contributes to the selection and proliferation of resistant bacteria.

For example, antibiotics used in agriculture, aquaculture, and veterinary medicine can be released into the environment through wastewater, manure, and runoff. This can result in the exposure of bacteria in the environment to low levels of antibiotics, which can promote the development of resistance.Environmental elements including temperature, pH, and the availability of nutrients can also have an impact on the development of resistance. Studies have demonstrated that some environmental factors can encourage the growth of resistant bacteria and that environmental stressors can speed up the rate at which bacteria gain resistance.

AMR can also develop as a result of the use of antimicrobials and other disinfectants in homes, food processing facilities, and healthcare institutions. The selection of resistant bacteria and the spread of resistance genes across bacteria can both be caused by the excessive or incorrect use of disinfectants.

Therefore, in order to create effective methods to stop the transmission of resistance, it is essential to understand how environmental factors contribute to the emergence of AMR. This includes measures such as reducing the use of antibiotics in agriculture and veterinary medicine, improving wastewater treatment processes and promoting proper use of disinfectants.

7.4. CONSEQUENCES OF ANTIMICROBIAL RESISTANCE

Human health is significantly impacted by antimicrobial resistance (AMR), which leads to greater rates of morbidity and mortality, longer hospital stays, and more expensive healthcare. It may also have financial repercussions, such as decreased productivity and higher healthcare costs. Antibiotic residues and resistant bacteria may contaminate soil and water resources, contributing to the environmental effects of AMR. In order to combat this worldwide public health concern, it is imperative to address AMR. To do this, efforts must be made to encourage responsible antibiotic use, develop novel antibiotics and alternative treatments, and enhance infection prevention and control procedures and increase awareness of the significance of AMR.

7.4.1 IMPACT OF AMR ON HUMAN HEALTH

Human health is significantly impacted by antimicrobial resistance (AMR), with rising resistance levels resulting in higher rates of morbidity and mortality. The effect of AMR on human health will be covered in this part, with a focus on the most prevalent resistant infections and related disorders.

Table 7.1

Pathogen	Disease	Impact of AMR
Staphylococcus aureus	Skin infections, pneumonia, sepsis	Methicillin-resistant Staphylococcus aureus (MRSA) infections are linked to greater rates of morbidity and mortality, longer hospitalisations in hospitals, and more expensive medical care.
Escherichia coli	Urinary tract infections, sepsis	E. coli infections that produce the extended-spectrum beta-lactamase (ESBL) are linked to greater rates of morbidity and mortality, extended hospital admissions, and more expensive medical care.
Klebsiella pneumoniae	Pneumonia, sepsis	Infections with Carbapenem-resistant Klebsiella pneumoniae (CRKP) are linked to greater rates of morbidity and mortality, longer hospital admissions, and more expensive medical care.
Acinetobacter baumannii	Pneumonia, sepsis	Acinetobacter baumannii (CRAB) infections are linked to greater rates of morbidity and mortality, longer hospital admissions, and more expensive medical care.

Pseudomonas aeruginosa	Pneumonia, sepsis	Multidrug-resistant Pseudomonas aeruginosa (MDRPA) infections are linked to greater rates of morbidity and mortality, longer hospitalisations in hospitals, and more expensive medical care.

As can be seen from the above table, the impact of AMR on human health is significant, with resistant infections associated with higher healthcare costs. Impact on individual patients, AMR also has broader public health implications, including the potential for the spread of resistant pathogens within healthcare settings and the community.

Table 7.2: Examples of health consequences of AMR

Health Consequence	Examples of Infections
Treatment Failure	Pneumonia, Urinary tract infections
Prolonged Illness	Tuberculosis, Gonorrhoea
Increased Mortality	Bloodstream infections, Meningitis
ReducedTreatment Options	Methicillin-resistant Staphylococcus aureus
Increased Healthcare Costs	Extended hospitalization, Expensive drugs

This table highlights some of the major health consequences of AMR. Treatment failure can occur when antibiotics are no longer effective in treating infections, leading to prolonged illness and increased risk of complications. Increased mortality is also a concern, especially in the case of bloodstream infections and meningitis. Reduced treatment options are a particular concern with bacteria such as methicillin-resistant Staphylococcus aureus (MRSA), where infections can be difficult to treat and can spread rapidly. Finally, AMR also has economic consequences, with increased healthcare costs due to extended hospitalizations and the need for more expensive drugs.

It's important to note that the impact of AMR on human health can vary depending on the specific organism and the resistance mechanisms involved. However, this table provides a general overview of some of the health consequences that can occur when antibiotics are no longer effective in treating infections.

Following figure 6 gives the glimpes of expected deaths till 2050 due to various reasons in which due to AMR deaths are hightest.

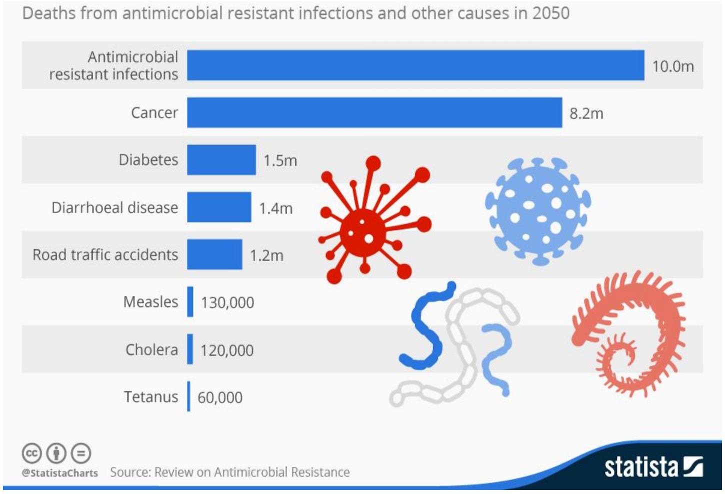

FIGURE 7.6: DEATHS FROM DRUG RESISTANT INFECTION SET TO SKYROCKET

Table 2 and figure 7 are giving the data of top 10 countries in which deaths details with AMR. (O'Neill, J. 2016).

TABLE 7.3: TOP 10 COUNTRIES WITH THE HIGHEST BURDEN OF AMR-RELATED DEATHS

Country	Number of deaths per year
India	58,000
Nigeria	33,000
Russia	10,000
Pakistan	9,700
Indonesia	9,500
China	8,700

United States	**5,400**
Egypt	**5,200**
Ethiopia	**4,900**
Democratic Republic of the Congo	**4,500**

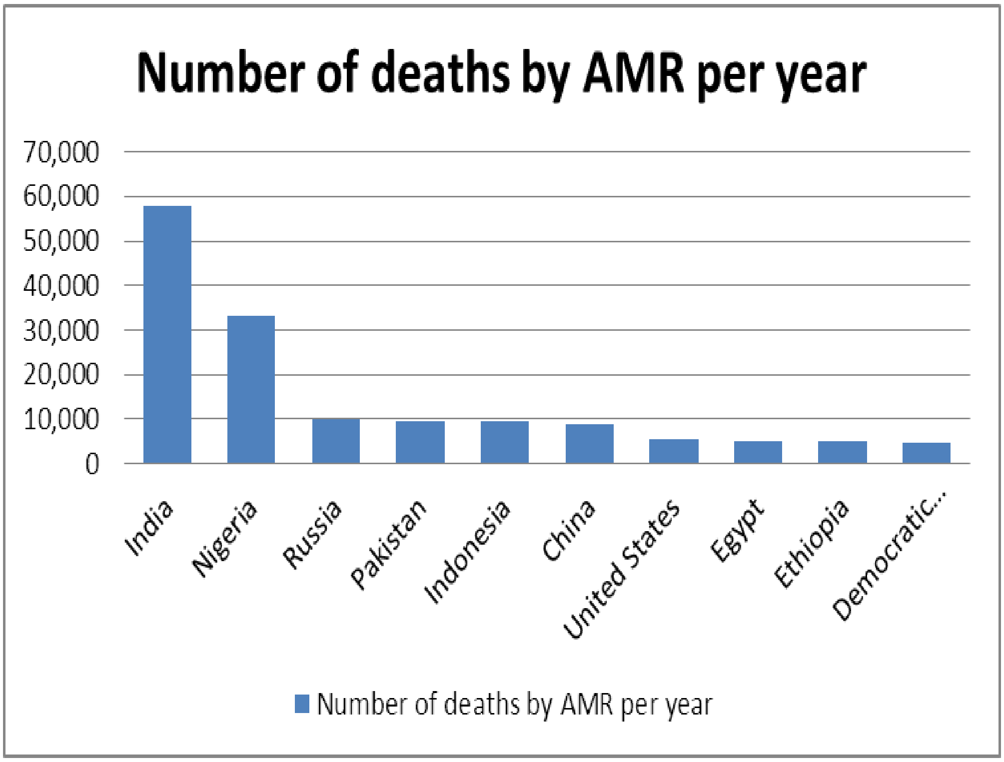

FIGURE 7.7: PICTORIAL REPRESENTATION OF NUMBER OF DEATHS PER YEAR BY AMR

7.4.2 ECONOMIC CONSEQUENCES OF AMR

Antimicrobial resistance has significant economic consequences globally. The loss of efficacy of antimicrobial agents can increase the duration and severity of infections, resulting in longer hospital stays, increased healthcare costs, and increased mortality rates.Some key economic consequences of AMR:

1. **INCREASED HEALTHCARE COSTS:** Treating illnesses that are resistant to antibiotics is far more expensive than treating infections that are treatable with these drugs. According to a study, antibiotic resistance increased healthcare expenditures in the US by $20 billion yearly. AMR is thought to have an annual economic impact of about €1.5 billion in Europe.

2. **LOST PRODUCTIVITY:** AMR has a big effect on the workforce. Patients who have resistant infections need to stay in the hospital longer, recover more slowly, and may need to take more time off work, which reduces productivity. According to one analysis, AMR might reduce GDP by 2 to 3.5% by 2050.

3. **AGRICULTURE AND FOOD PRODUCTION:** The use of antibiotics in food production and agriculture contributes to the development and spread of AMR. The consequences of AMR in agriculture and food production are the potential loss of crops, food contamination, and loss of livestock, leading to economic losses in the sector.

4. **INTERNATIONAL TRADE:** AMR also has a significant impact on international trade. The presence of resistant bacteria in food and animals can lead to import bans and trade restrictions, which can significantly impact the economies of exporting countries.

5. **RESEARCH AND DEVELOPMENT:** Creating new antibiotics requires a costly and drawn-out procedure. Investment in antibiotic research and development has decreased as a result of the financial burden of AMR. For the sake of global health, the dearth of new antibiotics being developed to combat resistant illnesses is a serious issue.

TABLE 7.4: ECONOMIC CONSEQUENCES OF AMR

Consequences	Examples
Increased Healthcare Costs	The United States spends an additional $20 billion in healthcare costs annually due to AMR
Lost Productivity	AMR could result in the loss of 2 to 3.5% of GDP by 2050
Agriculture and Food Production	AMR can lead to the loss of crops, food contamination, and loss of livestock

International Trade	The presence of resistant bacteria can lead to import bans and trade restrictions
Research and Expansion	Absence of new antibiotics in the queue for treating resistant infections

In nutshell, the economic consequences of AMR are significant and impact healthcare costs, lost productivity, agriculture and food production, international trade, and research and development. The global community needs to take steps to address AMR to mitigate its economic impact on societies.

7.4.3 CONSEQUENCES OF AMR ON THE ENVIRONMENT

Antimicrobial resistance has significant consequences on the environment as well. Some examples of the impact of AMR on the environment:

- **CONTAMINATION OF WATER BODIES:** Antibiotics and resistant bacteria can enter the environment through various pathways, such as wastewater treatment plants, agricultural runoff, and animal waste. This can lead to contamination of water bodies which can have adverse effects on aquatic ecosystems and the organisms living in them.

- **SOIL POLLUTION:** Both antibiotic-resistant bacteria and antibiotic-resistant bacteria can build up in soil and cause soil pollution. Plant development and survival as well as the survival of soil microbes may be negatively impacted by this.

- **DISRUPTION OF NUTRIENT CYCLING:** The maintenance of healthy ecosystems depends on the efficient cycling of nutrients, which can be interfered with by the existence of antibiotic-resistant bacteria in the environment. For instance, antibiotic-resistant bacteria can interfere with the decomposition and recycling of organic matter in the soil which can disrupt the availability of nutrients.

- **TRANSMISSION OF RESISTANCE GENES:** The transmission of antibiotic-resistant bacteria and their resistance genes from the environment to people and other animals is a major factor in the spread of AMR. Direct exposure to contaminated food, water or soil can also cause this, as well as eating animals that have used antibiotics.

Some unique facts and percentages regarding the consequences of AMR on the environment:

TABLE 7.5: FACTS RELATED WITH AMR

Consequence of AMR	Facts
Increase in greenhouse gas emissions due to antibiotic production	2.5 million metric tons of CO2 equivalent per year (0.1% of global greenhouse gas emissions)
Antibiotic residue in soil leading to reduced crop yields	8-12% reduction in crop yields
Increase in antibiotic resistance genes in soil and water	70% of global antibiotic consumption ends up in the environment
Disruption of aquatic ecosystems due to antibiotic pollution	53% of monitored rivers in Europe have antibiotic concentrations above safe levels
Potential loss of biodiversity due to antibiotic pollution	In aquatic ecosystems, the abundance of some bacterial species can increase by 10,000 times due to antibiotic pollution, leading to a loss of biodiversity

The substantial effects of AMR on the environment are highlighted in Table 3.0, including the release of greenhouse gases, decreased crop yields, and disruption of ecosystems. Additionally, the issue of AMR may become worse due to a rise in antibiotic resistance genes brought on by drug residue in soil and water. In order to preserve the sustainability of our world and the wellbeing of its inhabitants, it is crucial to address these effects.

7.4.4 CHALLENGES IN TACKLING AMR

One of the biggest challenges to public health that the world currently faces is antimicrobial resistance (AMR). The World Health Organization (WHO) has emphasized that AMR is a global crisis with the potential to result in millions of deaths if immediate action is not taken.

7.4.4.1 REASONS WHY TACKLING AMR IS ESSENTIAL

There are several reasons why tackling AMR is essential.

- Increasing prevalence of AMR means that previously treatable infections are becoming resistant to the available antibiotics.
- AMR also poses a significant economic burden. The increased healthcare costs associated with treating resistant infections can be substantial, particularly in low income countries. The loss of productivity due to illness and mortality can also have a significant impact on the economy.
- Spread of AMR is not limited by geographical borders, and it can quickly become a global problem. Therefore, a coordinated global response is required to tackle the issue. This includes developing new antibiotics, improving antibiotic stewardship, and increasing awareness and education around the appropriate use of antibiotics.

7.5 SOLUTIONS TO ANTIMICROBIAL RESISTANCE

Antimicrobial resistance is a world-wide community wellbeing issue that requires collaborative efforts to develop and implement solutions. Some of the solutions to combat AMR include:

TABLE 7.6: SOLUTIONS TO ANTIMICROBIAL RESISTANCE

Solution	Descriptions
Improved infection control	Good hygiene and infection control practises can help reduce the spread of resistant microbes in healthcare settings.
Development of new antibiotics	New antibiotics must be studied and developed in order to stop the growth of resistance.
Antibiotic stewardship programs	Programmes that prohibit inappropriate use and promote optimal use help to maximise antibiotic use.
Education and awareness	Patients, healthcare professionals, and the general public are all being educated on how to use antibiotics properly.
Alternative therapies	By adopting complementary and alternative medicine to treat infections, the need for antibiotics can be reduced.
Improved diagnostics	With the aid of enhanced diagnostics, the exact bacteria that cause an infection can be identified, and the appropriate course of action can be decided.

Solution	Descriptions
Reduction of antibiotic use in agriculture	The development of germs that can infect humans with drug-resistant strains of bacteria can be halted by reducing the use of antibiotics in animal husbandry.
Global coordination and action	To combat the transnational threat posed by antimicrobial resistance, cooperation between governments, international organisations, and stakeholders is required.
Research into new technologies	More specialised and efficient treatments for infections can be created with the use of new technology.
Investment in research and development	The creation of novel medicines and alternative therapies must be continually researched and developed in order to combat antimicrobial resistance.

7.5.1 IMPORTANCE OF REDUCING UNNECESSARY USE OF ANTIBIOTICS IN ANIMAL AGRICULTURE

To prevent AMR, it is critical to reduce the usage of antibiotics in animal husbandry. The growth and spread of bacteria that are resistant to antibiotics is significantly facilitated by the use of antibiotics in animal agriculture. Antibiotics are frequently administered to animals in order to stimulate growth and prevent sickness, which results in antibiotic overuse and misuse. Humans come into direct touch with antibiotic-resistant bacteria from animal agriculture, eat tainted food, and are exposed to them in the environment.

Several methods, including enhancing animal health and welfare, minimizing the use of antibiotics for growth promotion, and encouraging the use of alternative therapies like vaccinations and probiotics, have been suggested as ways to reduce the needless use of antibiotics in animal agriculture. In addition, enacting stringent rules on the use of antibiotics in animal agriculture, improving surveillance and monitoring systems and giving farmers and veterinarian’s instruction and training can all help reduce the unneeded use of antibiotics.

It is crucial to cut down on the usage of antibiotics that isn't necessary in animal agriculture. By using fewer antibiotics, we can prevent the emergence and spread of germs that are resistant to them, preserving their usefulness for both human and animal health. To preserve the availability of antibiotics for future generations, it is a crucial step to encourage their sustainable and appropriate usage.

TABLE 7.7: ANTIBIOTIC USE IN ANIMAL AGRICULTURE (NATIONAL RESOURCES DEFENCE COUNCIL. 2017

Antibiotic usage statistics	Facts
Amount of antibiotics used in animal agriculture	70-80% of all antibiotics sold in the US
Percentage of antibiotics fed to healthy animals	80%
Global livestock population	~23 billion animals
Antibiotic consumption per animal	Varies widely by country, up to 4 times the rate of humans
Antibiotic-resistant infections in humans associated with animal agriculture	400,000 cases per year

7.5.2 ROLE OF RESEARCH AND DEVELOPMENT IN FINDING NEW ANTIBIOTICS AND ALTERNATIVE TREATMENTS

Research and development plays a critical role in finding new antibiotics and alternative treatments to combat antimicrobial resistance. The invention of new antibiotics is a complex and lengthy mechanism that can take years and requires significant investment. The following are some key strategies for promoting research and development in this area: (World Health Organization. 2015).

i. **FUNDING:** To assure the development of new antibiotics and other therapies, governments and commercial organizations must invest in research and development. The creation of novel technologies, clinical trials, and early-stage research should all receive funding from this source.

ii. **FINANCIAL INCENTIVES:** Governments can provide businesses that create new antibiotics tax discounts and patent extensions. This may entice pharmaceutical firms to make investments in the creation of fresh antibiotics and complementary therapies.

iii. **COOPERATION:** To assure the development of novel antibiotics and alternative treatments, cooperation between researchers, physicians, and industry is crucial. This partnership may aid in accelerating the process of developing new therapies and increasing their efficacy.

iv. **REGULATORY REFORM:** novel regulatory frameworks are required to support the creation of novel antibiotics and complementary therapies. This includes accelerating and streamlining the approval procedures for novel medicines.

v. **PUBLIC-PRIVATE** partnerships can be an effective instrument in the creation of novel antibiotics and complementary therapies. These collaborations can combine the knowledge and resources of the public and commercial sectors to create novel treatments more swiftly and successfully.

vi. **RESEARCH INTO ALTERNATIVES:** To ensure that new treatments are available in the fight against antimicrobial resistance, research into alternatives, such as probiotics and phage therapy, is crucial.

Research and development is a critical component of the fight against antimicrobial resistance. The strategies outlined above can help to ensure that new antibiotics and alternative treatments are developed to combat this growing public health threat.

7.5.3 ROLE OF RESEARCH AND DEVELOPMENT IN FINDING NEW ANTIBIOTICS AND ALTERNATIVE TREATMENTS:

Antimicrobial resistance (AMR) is a global public health threat that requires international collaboration to tackle effectively. Here are some reasons why international collaboration is essential in addressing AMR: **(The Review on Antimicrobial Resistance, 2016).**

i. **GLOBAL SPREAD OF AMR:** Infectious diseases and resistance to antimicrobial agents can easily spread across national borders due to increased travel and trade. International cooperation is therefore, necessary to ensure the coordinated global response to the challenge of AMR.

ii. **SHARED RESPONSIBILITY:** Antimicrobial resistance is not only a national but also a global public health concern, and all countries have a shared responsibility to reduce its impact. International collaboration allows countries to work together to share knowledge and expertise, coordinate efforts, and support each other in their efforts to combat AMR.

iii. **LIMITED RESOURCES:** Many low- and middle-income countries may have limited resources to address the challenges of AMR. International cooperation can help these countries to access the necessary funding, expertise, and technology required to tackle AMR.

iv. **INTERNATIONAL GUIDELINES:** International collaboration can help develop and disseminate guidelines for the appropriate use of antimicrobial agents, infection control, and surveillance, which can help to reduce the development and spread of AMR.

v. **GLOBAL RESEARCH EFFORTS:** International collaboration is essential in promoting global research efforts aimed at finding new antimicrobial agents and alternative treatments for infectious diseases. Collaboration between different countries can enable sharing of knowledge, expertise and resources and accelerate research efforts to develop new treatments.

Overall, international collaboration is crucial in addressing AMR effectively. It can help to promote the appropriate use of antimicrobial agents, develop new treatments and guidelines, and support countries with limited resources. Through international collaboration, it is possible to reduce the impact of AMR and ensure the continued efficacy of antimicrobial agents in treating infectious diseases.

7.5.4 THE NEED FOR PUBLIC EDUCATION AND AWARENESS ABOUT AMR

In order to combat antimicrobial resistance, there is a critical need for public education and understanding regarding AMR.

The general public's lack of knowledge regarding the safe use of antibiotics and the effects of inappropriate usage can result in the overuse and misuse of antibiotics. Infections that are resistant to antibiotics may consequently become more common.

To inform the public about the value of using antibiotics only when absolutely necessary, finishing the entire course of treatment, and correctly disposing of antibiotics, effective communication tactics are required. (European Centre for Disease Prevention and Control. 2021). **Table 7.8** deals with importance of public education and awareness.

TABLE 7.8: IMPORTANCE OF PUBLIC EDUCATION AND AWARENESS ABOUT AMR

Facts about AMR	Importance of public education and awareness
Overuse and misuse of antibiotics	Leads to development of antibiotic-resistant infections
Inappropriate antibiotic use	Increases risk of AMR
Effective communication strategies	Needed to educate public on proper use of antibiotics
Importance of completing full course of treatment	To prevent development of antibiotic-resistant infections
Healthcare providers and policymakers	Can raise awareness about risks of AMR and importance of appropriate antibiotic use
Only prescribe antibiotics when necessary	To reduce overuse and misuse of antibiotics
Choose most appropriate antibiotic	To prevent development of antibiotic-resistant infections
Use shortest effective course of treatment	To prevent development of antibiotic-resistant infections

In addition, the public can be educated about AMR with the help of legislators and healthcare professionals. Through campaigns, instructional materials, and open forums, they can increase public knowledge of the dangers of AMR and the significance of prudent antibiotic usage. Additionally, doctors may significantly reduce the overuse of antibiotics by only prescribing them when absolutely required picking the best antibiotic, and following the quickest most efficient course of therapy.

7.6. CONCLUSION

The important problem of antimicrobial resistance (AMR), its sources, effects, and potential treatments have all been covered in this chapter. The alarming increase of AMR on a global scale, the contribution of excessive and improper antibiotic usage to the emergence of AMR, and the significance of research and development in the quest for novel antibiotics and complementary therapies are just a few of the chapter's major issues. AMR's negative effects on the economy, the environment, and human health were also emphasized.

Strategies like encouraging appropriate antibiotic usage, cutting back on needless antibiotic use in animal husbandry, and international cooperation were suggested as ways to combat AMR. Furthermore, the significance of AMR education and public awareness was emphasized.

To stop the establishment and spread of bacterial strains that are resistant to treatment and to maintain the efficacy of antibiotics in the treatment of infectious illnesses, it is critical to take action against AMR. In order to confront this threat to global public health and create new therapies and alternative methods of battling infectious diseases, more research and collaboration are required.

In conclusion, governments, healthcare workers, researchers, and the general public must work together if AMR is to have a bright future. To combat AMR and preserve the availability and efficacy of antibiotics for upcoming generations, we must collaborate to develop and execute effective measures.

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