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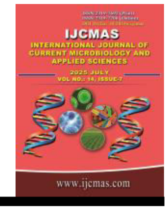

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Confronting Antimicrobial Resistance across Humans, Animals, and the Environment: Integrating the One Health Approach

S. Arul Jothy[1], M. Prakash[1*], K. Arivazhagan[2], S. Saranya[3] and R. Sabarish[4]

[1]Research Department of Microbiology, Kanchi Shri Krishna College of Arts and Science, Kanchipuram, 631 551, Tamil Nadu, India
[2]Department of Microbiology, Lakshmi Bangaru Arts and Science College, Pallipettai, Melmaruvathur-603 319, Chengalpet District, Tamil Nadu, India
[3]PG & Research Department of Zoology, Justice Basheer Ahmed Sayeed College for Women, Teynampet, Chennai-600 018, Tamil Nadu, India
[4]Department of Biotechnology, St.Joseph's College (Arts & Science), Kundrathur Main Road, Kovur, Chennai, 600128, India

**Corresponding author*

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ABSTRACT

Antimicrobial resistance (AMR) represents one of the most critical threats to global health, food safety, and sustainable development in the 21st century. The rapid emergence and dissemination of resistant microbial strains compromise the effectiveness of antimicrobial agents, rendering common infections increasingly difficult to treat. A key driver of AMR is the widespread, and often indiscriminate, use of antibiotics across multiple sectors—including human healthcare, veterinary medicine, and agriculture. In particular, intensive livestock production systems are recognized as significant contributors to AMR due to the routine use of antimicrobials not only for therapeutic purposes but also for prophylaxis and growth promotion. This extensive usage fosters the selection pressure that promotes the evolution of multidrug-resistant bacteria within animal populations. These resistant pathogens, along with their resistance genes, can be transmitted to humans through direct contact with animals, consumption of contaminated animal products, and via environmental pathways such as water bodies, soil, and air polluted with animal waste. The interconnectedness of humans, animals, and the environment underlines the need for a comprehensive One Health approach to address AMR. This review summarizes the major causes of AMR in humans, livestock, and environmental systems, and explores the complex mechanisms by which resistance develops and spreads. Additionally, current global and regional strategies aimed at mitigating AMR are discussed, including antimicrobial stewardship programs, surveillance networks, regulatory policies, alternatives to antibiotics, and public awareness campaigns. Strengthening intersectoral coordination, enforcing responsible antimicrobial use, and investing in research and innovation are pivotal to curbing this global health crisis. A holistic and sustained effort is essential to preserve the efficacy of existing antimicrobials and to safeguard public and animal health in the long term.

Introduction

Antibiotic Resistance (AR) is a complex and serious thread to both livestock's, humans as well as for environment. If AR rise globally if this continuous than by 2050 10 million people will die by Drug-resistant infection. Bacteria species such as *E.coli, Salmonella, Campylobacter* carry antibiotic resistant gene which can spread between livestock's human and environment.

In 2019 5million human deaths were associated by bacterial antimicrobial resistant worldwide (https:///www.fao.org). One health approach defined as a joint effort of various disciplines such as animal, human and environment health. The one health is originated in 19th century introduced by Rudilf Virchow by term 'Zoonosis' which means the relationship between human and animal health. He established the idea of "ONE MEDICINE" reinforcing the close connection between human and animal treatment (Maria Elena Velazguez-Meza *et al.,* 2022). It is estimated that 60- 70% of diseases that is spreading to human are emerged and re-emerged are zoonotic diseases originated from animals and also 30 New human pathogens developed over 3 decades in this 70% of the pathogens are originated from animals. One health approaches developed to range of issues such as Antimicrobial Resistant (AMR) and for Zoonotic diseases (WHO). Antimicrobial agents are used in terrestrial animal production to prevent Zoonosis growth of the animals. Antimicrobials used so much in animal production especially in pig and poultry production Antimicrobial used as double. Mostly Antimicrobial used for therapeutic uses and for disease prevention. In recently demand for Animal production products increased rapidly Because of this overall use of antimicrobials increased a lot. In food producing animals, AMR poses a serious threat to the safety and live hoods (Sara Babo martins *et al.,* 2024). The fundamental resistant of the AMR in livestock is Antibiotic deactivation, efflux pumps and target specific etc. The Most common detected ARG classes in the livestock waste such as tet, sul, erm, fca and bla (Ya He *et al.,* 2020). The livestock sector contributes 30.87% of the Agriculture and allied sector Gross value Added (GVA) 6.17% GVA. India ranks 3rd in egg production and 8th in meat production in the world because of the demand of the demand of the animal products in India lot of antimicrobials used in the animal production sectors. Cephalosporin resistance has become more common pathogens used to manage cases of bovine mastitis and also there is huge mortality rate due to bacterial pneumoniae in food animals. In livestock's sector preliminary analysis revealed that *E.coli* generally resistant to amikacin, ampicillin, cefotoxime. Isolates of avian and porcine sources more frequently Antibiotic resistant than the isolates from the bovine and caprine sources. India is also high in producing milk. Milk production by buffaloes (56%) of the total milk production in India. Mastitis is major problem in bovine. Food borne bacteria includes *E.coli*, Proteus spp, *Klebseilla* spp, *Staphylococcus aureus*, Streptococcus spp and cornybacterium spp have been reported India (Florence Mutua *et al.,* 2020).

AMR in Human

Antimicrobial resistance in human is a developing global health concern in which bacteria, viruses, fungi, and parasites develop resistance to the effects of drugs that were once successful against them. Treatment becomes more difficult as a result of this resistance, increasing the chance of death, lengthening sickness, and raising medical expenses. The overuse and misuse of antimicrobial agent is one of the main reasons for Antimicrobial resistant in human. Incorrect antibiotic selection by healthcare providers. Patients stopping antibiotics once symptoms improve, not completing full course is also main reasons for AMR. Several classes of antibiotics are widely used in human medicine, but resistance to these drugs has become a serious concern globally. Beta-lactams including pencillins, cephalosporins and monobactams are most commonly prescribed antibiotics for respiratory tract infections, urinary tract infection and sepsis. Fluoroquinolones like ciprofloxacin and levofloxacin used for UTI and gastrointestinal infections. Carbapenems antibiotics used for UTI infections. Azithromycin used for STIs and travelers's diarrhea. Gentamicin and amikacin used for gram negative bacteria infections. Clindamycin used for skin and dental infections. Vancomycin commonly used for Hospital-Acquired infections. For multi-drug resistant gram negative bacteria colistin antibiotics commonly used.

These bacteria are harmful to humans because they are resistant to most antibiotics, making it difficult to treat the diseases they cause. An estimated 450 000 cases of MDR-TB were reported worldwide in 2012, of which 300 000 were incident cases. Over 20% of patients with a history of TB therapy and nearly 4% of all new TB diagnoses worldwide are thought to be MDR-TB. The three most prevalent NTS stereotypes, *S. Enteritidis, S.*

typhimurium, and S. Heidelberg, are found in both domestic and wild animals worldwide and number over 1500. The prevalence of NTS infection has significantly increased in recent years. According to a study on the global burden of NTS, there are 94 million instances from NTS gastroenteritis annually, which leads to 155,000 deaths worldwide (Francesca prestinaci *et al.,* 2015). Thousands of people are hospitalized each year in developed nations like the United States due to antibiotic-resistant microbial infections; of these, an estimated 23,000 patients pass away due to a lack of available treatment options and the complex and deadly symptoms that these drug-resistant microorganisms cause, which are challenging to diagnose. In India it is estimated that more than 58,000 infants died in the year 2013 as a result of antibiotic resistant bacteria infections and over 40% of the world's antibiotics are produced in India (Irfan A. Rather *et al.,* 2017). The 20th century saw the emergence of MDR M. tuberculosis, a significant pathogen present in both industrialized and developing countries. *Acinetobacter baumannii, Burkholderia cepacia, Campylobacter jejuni, Citrobacter freundii, Enterobacter spp., Enterococcus faecium, Enterococcus faecalis, Escherichia coli, Haemophilus influenzae, Klebsiella pneumoniae, Proteus mirabilis, Salmonella spp., Serratia spp., Staphylococcus aureus, Staphylococcus epidermidis, Stenotrophomo-nas maltophilia, and Streptococcus pneumoniae* are among the other serious infections that are hospital-associated and this all bacteria are super-bugs which shows resistant to most antibiotics which makes treatment difficult (Julian Davies *et al.,* 2010). ESCAPE stands for *Enterococcus faecium, Staphylococcus aureus, Clostridiodies difficile, Acinetobacter baumannii, Pseudomonas aeruginosa and Enterobacteriaceae* are major hospital-acquired pathogens and this all known for its multidrug resistance which shows resistant to most antibiotics because of it difficult to treat and this all organisms are associated with high morbidity, mortality rate.

AMR In Livestock's

AMR In Bovine

Milk is a sterile thing produced by bovine. It is a component present in the healthy udder cells. Milk as a high nutrient value and it has a neutral PH which makes it suitable for numerous microorganisms to grow. The most common infection in bovine is mastitis. It is udder infection which is most contaginous infection. The resistant pathogens that present in the milk which causes mastitis infection are *Staphylococcus aureus*, *Streptococcus agalactiae, cornyebacterium bovis, Mycoplasma bovis*. Nearly 48% of gram negative bacilli presented in cow and buffaloes milk shows complete resistant to beta-lactamases antibiotics and also shows resistant to oxytetracycline. Gram positive organisms such *Staphylococcus spp* shows resistant to Vancomycin, methicillin (Neelam Taneja *et al.,* 2019). *Staphylococcus aureus* common microrganisms which causes superficial and invasive infections. S.aureus resistant to ciprofloxacin, gentamicin, linezoild, oxacillin and vancomycin. *Trueperella pyogenes* causes mucus layer of upper respiratory, urogenital and GI tracts of livestock. Bovine foot rot(BFR) is also one of the infection in beef and dairy cattle caused by *Porphyromonas levii, Prevotella intermedia.* Bovine respiratory diseases caused by *Mannheimia haemolytica and Histophilus somni.* Calf diarrhea is mainly caused by rotavirus. The most significant bacterium that causes mastitis is *Streptococcus agalactiae*, which also causes bacteremia and other illnesses in cattle, including skin infections.

All of these diseases get into milk through the hands of milkers and bacterial contaminated equipment. Nearly 45% of cow mastitis infections in India are caused by *staphylococcus* species, which are resistant bacteria found in milk. In India, streptococcus is also a common cause of mastitis infections in cows (Krishnamoorthy *et al.,* 2017). *Staphylococcus aureus* and *Escherichia coli* are the most-common causes of contagious and environmental clinical mastitis. Methicillin-resistant S. aureus (MRSA) have been isolated from mastitis milk samples. The *E.coli* had highest resistance to penicillin(63%) followed by amoxicillin (52.1%), oxytetracycline (47.95) and methicillin (45.4%). The *Staphylococcus aureus* showed highest resistance to penicillin (63.5%) followed by amoxicillin (61.5%), oxytetracycline (49%) and methicillin (52.9%) (Chandrasekaran *et al.,* 2015).

AMR In Poultry

The use of antibiotics in poultry production is used a lot for non-theuraputic purposes such as used as a growth factor and also it improves poultry performances effectively and economically at the sometime, because of overuse of antibiotics in poultry and livestock production pathogenic and non-pathogenic organisms become resistant to multi-antimicrobial agents (Christian Agyare *et al.,* 2018). Septicemic bacterial infection is common in chicken and turkey which is caused by *E.coli* (Philip M. Panyanko, *et al.,* 2022). It is commonly present in the intestine and it can be opportunistic systematic infection and other common infection in poultry is mycoplasma infection such as *M.gallisepticum* and *M.synaviae* (Hector M. Cervantes *et al.,* 2015). *Escherichia coli* shows 97% which resistant to tetracycline, 51% ampicillin and 31% piperacillin. Staphylococci resistant to Erythromycin 39%, clindamycin 19%, tetracycline 14%, ofloxacin 13%. Enterococci shows high resistant to tetracycline 80%, 59% erythromycin, 34% nitrofurantoin, 51% ofloxacin (Apata *et al.,* 2009).

Enterobacteriaceae, E.coli, S. pullrom, S.gallinarum, Haemphilus paragallinarum this all bacteria commonly present in the poultry. *E.coli* shows highest resistant such as Ampicillin, Streptomycin, Gentamycin, Chloramphenicol, Tetracycline, Ciprofloxacin and Enrofloxacin. *A.paragallinarum* shows highest levels of resistance 70% to erythromycin and tetracycline and it also shows resistant for penicillin, gentamycin and co-trimoxozole for 20-50%. *P. multocida* shows resistant to erythromycin (Nguyenthi Nhung *et al.,* 2017). Colibacillosis that is Avian pathogenic *Escherchia coli* (APEC) is one of the major challenging faced by the poultry industry as it causes serious infection to poultry. Antibiotics such as Tetracyclines, aminoglycosides, penicillins, quinolones are commonly used antibiotic for treatment but recently APEC shows resistant to most antibiotics used to treat infection. In India Poultry farming has grown significantly in the last several decades. Now India one of the largest producers in poultry meat and eggs globally. In new study has founded that hifh level of AMR in poultry farm enivronment in Tamil Nadu, Andhra pradesh. India accounts for 3% of the global consumption of Antimicrobial s in food animals and has one of the highest intensity of antimicrobial usage (AMU) rates in the livestock's sector.

Reasons for the antibiotic resistant in poultry is due to the overuse and misuse of antibiotics. Poor farm management such as overcrowding, inadequate hygienic and stress among birds increases prevalence leading to overuse of antibiotics. Inadequate guidelines regarding the use of antibiotics for the treatment of animals.

AMR In Aquaculture

Aquaculture systems encompass a diverse range of environments including freshwater, salt water, coastal, riverine and land-based tropical and temperature climates. A variety of microorganisms coexist with aquatic organisms some of which may be harmful depending upon several factors. The majority of the infections that kill aquatic animals in aquaculture are aerobic gram negative rods. In 2012, the FAO UN reported trimethoprim/sulfadizine and Oxytetracycline Florfenicol are commonly used antibiotics in aquaculture. During treatment for both chronic and sub therapeutic levels antimicrobial agents are used. Global antimicrobial consumption in aquaculture in 2017 was estimated that 10,259 tons and it may increase 33% between 2017 and 2030. The share of aquatic animal production output in India is 9.9%. The use of antimicrobial in aquaculture is on the rise with 10,259 tones used in 2017 can go upto 13,600 tonnes by 2030 (Gianluigi Ferri *et al.,* 2022).

The bacteria that causes following illness such as Salmonellallosis, Pneumonia, Tuberculosis, Septicemia, Edwardisellosis, furunculosis are exhibit resistance to the majority of antimicrobial agent which makes treatment challenging. *Aeromonas hydrophila, Vibrio vulnificus, Streptococcus iniae, Photobacterium damselae* and *Mycobacterium marinum* are examples of zoonatic pathogens that spread across the enviroment by carrying the ESBL genes (Meldea G. bondad-Reantaso *et al.,* 2022). This bacteria also carries resistant gene such as lactamase resistant gene includes blaTEM-52, blaSHV-12 as well as Cm1, tetA, aadA, Sul1, Sul2 and Sul3. Some emerging plasmid-mediated quinolone-resistance (PMQR) genes found in aquatic pathogens such as *Vibrio, Shewanella and Aeromonas*, beta-lactamase genes is also seen in *photobacterium damselae* and *oceanobacillus iheyenis*. Marine strains of photobacterium, Vibrio, Alteromonas and Pseudomonas transfer tetracycline resistance by conjugation method (Lucia Santos *et al.,* 2018).

Fish

In Fish farming nearly 73% of oxytetracycline, florfenicol and sulphadiazine and 55% of Amoxicillin, Sulphadimethoxine and Enrofloxacin. Antimicrobial agent used orally with food or directly added to water to treat diseased fish. The most commonly used ornamental fish industry are chloramphenicol and followed by oxytetracycline and erythromycin and some other antibacterial agents are Nitrofurans, quinolones. Oxytetracycline is a board spectrum antibiotic used as both bath aswellas feed treatment. For gram negative bacteria Antibiotics such as Aminoglycosides and neomycin are injected in fish (Akansha Tiwari, *et al.,* 2024). In a recent study of Antimicrobial susceptibility in 64 strains of Aeromonds was tested and found that it shows resistant to most major antibiotics such as Ampicillin, erythromycin, penicillin, sulfanamide etc. Most pathogenic bacteria that causes infection in the oramental fish are gram negative bacteria such as Aeromonas, Flavobacterium columnare, Vibrio and Pseudomonas.

For gram positive bacteria Streptococcus that commonly causes diseses in fish. The common diseases in fish are Aeromoniasis or ulcer, fin and tail rot by Aeromonas spp, columnaris diseases caused by Flavobacterium columnare, Mycobacteriosis by *Mycobacterium fortuitum*, Dropsy by *Aeromonas hydrophila*, Wool diseases by *Saprolegnia parasitica*. Most common parasitic diseases is 'Ich'or 'White spot diseases' caused by *Ichthyophthirius multifilis*. In India *staphylococcus, E.coli, Aeromonas* was isolated from Freshwater aquaculture.

In shrimp Bacteria such as *Staphylococcus aureus*, *E.coli, Vibrio parahaemolyticus.* Freshwater isolates show resistant to Penicillin 91%, Ciprofloxacin (54.8), Erythromycin (34.3%) and Cefoxitin (28%). In marine fish isolates it shows resistant to penicillin (79.2%) (INFAAR- analytical report).

Shrimp

Shrimp farming has been a traditional way of life for years *Panaeus vannamei* and *Penaeus monodon* are two main penoid shrimp spp. The important bacterial pathogens which causes diseases are in shrimp are *Vibrio spp, Pseudomonas spp, Aeromonas spp*. A wide range Antibiotics and other antimicrobial agents including heavy metals, fungicides and antiparasitics are used in shrimp aquaculture. *Enterococcus* isolated from farm raised shrimp sample 95% were resistant to at least 1 antibiotic among 16 antimicrobial agents where us *Enterocci* isolated from wild shrimp shows resistant 89% and also isolates shows highest resistant to Linocmyin, Ciprofloxacin, Linezoild (Brad Hirshfeld *et al.,* 2023). Vibrio isolates were resistant to ampicillin, cefoxitin and it shows lowest resistant to tetracycline. Salmonella strains isolated from shrimp show resistant to one or more antibiotics such as AMP, OTC, TET and NIT. In that some of the Salmonella strains shows resistant to three antibiotic classes such as pencillin, tetracycline and nitrofuran (Fatima C. T. Carvolho *et al.,* 2013). The common pathogens that causes infection in shrimp are *Vibrio parahaemolyticus, Vibrio vulnificus and Vibrio alginolyticus*. The common zoonatic infection are vibriosis, appendage and cuticular vibriosis and Septic hepatopancreatitis.

AMR In Sheep and Goat

Gram positive bacteria isolated from sheep are *Enterococcus faecium, Staphylococcus aureus, Staphylococcus epidermidis, Staphylococcus arlettae, Enterococcus casseliflavus, Staphylococcus warei, Staphylococcus kloosi, Enterococcus durans, Enterococcus faecalis, and Lactococcus lactis. Staphylococcus capitis, Staphylococcus sciuri, Staphylococcus simulant, Staphylococcus chromogens, Staphylococcus intermedius, Staphylococcus hyicus.* This isolates show resistant to pencillin, Ciprofloxacin, Teyracycline Staphylococcus resistant to all antibiotic which was tested. Gram negative bacteria isolates are *Escherichia coli, Aeromonas caviae, Aeromonas sobria, Campylobacter spp., Salmonella Dublin, Mannheimia haemolytica, Pasteurella multocida, Enterobacter intermedius, Proteus vulgaris, Citrobacter diversus, Yersinia spp., and Yersinia* and this isolates show resistant to most antibiotic such as pencillin and first generation cephalosporin (Okti Herawati *et al.,* 2023). Among the other livestock's for sheep and goat lot of antibiotics used. Antibiotics used in lambs/kids to treat pneumonia infection and diarrhea. The Zoonatic infections in sheep, goat are campylobacteriosis (*Camphylobacter jejuni, Camphylobacter coli*), Salmonellosis (*Salmonella typhi*), Listeriosis (*Listeria monocytogenes*), Ceyptosporidiosis (*Cryptosporidium Parvum*), Ringworm infection. Following organisms isolated from fecal sample of sheep such as *E. coli, Salmonella spp., Shigella spp., S. aureus, and S. saprophyticus.* This isolates shows resistant to Ampicillin 79%, Cephalothin 70.6%, Vancomycin 65%, Gentamicin 63.3%, Tetracycline 41.6% (Ashesh Basnet *et al.,* 2024).

AMR In Environment

The environment serves as a reservoir for the transmission of resistance genes and microorganisms. The Waste from humans and animals, which includes antibiotics and resistant bacteria, contaminates, rivers, lakes and soil. Hospitals and the pharmaceutical sector release antibiotics waste. These Antibiotic leftovers buildup in the soil, which can promote the spread and development of resistant genes. The three primary economic sectors that plays a role in AMR are the production of Pharmaceuticals, agriculture food systems and health care services A significant factors is the inadequate disposal of antibiotics from homes, hospitals and Pharmaceutical companies, which permits active drug substances to infiltrate soil and water systems.

The environment is key to antibiotics resistance. Wastewater Treatment Plants (WWTPs) Major hot spots for antibiotic-resistant bacteria (ARB) and antibiotic resistance genes (ARGs) due to the accumulation of domestic, hospital, and industrial waste. Bacteria in soil and seawater can develop Resistance through contact with resistant bacteria, Antibiotics and disinfectant agents released by human Activity. People and livestock can then be exposed to more resistant bacteria through food, water and air. Antibiotic Resistant bacteria maybe present in raw sources water and treated drinking water.

In India AMR bacteria and their genes have been reported from various water sources. The major sources are the pharmaceutical waste water and hospitals effluents are released into the near water bodies without proper treatment. The isolated *E.coli* resistant to third generation cephalosporin was 95%. ESBL 17.4% among gram negative bacteria isolated has resistant genes like bla NDM-1 and bla OXA48 (Neelam Tanjena *et al.,* 2019). Common Resistant Bacteria Isolated from Environment are *Escherichia coli Klebsiella pneumoniae, Pseudomonas aeruginosa, Acinetobacter baumannii, Enterococcus faecalis and Staphylococcus aureus* (Multiple antibiotic resistance has been observed in bacteria obtained from a variety of environmental sources, including soil, water, and industrial waste.

Escherichia coli, Pseudomonas aeruginosa, and Enterococcus faecalis are among the multidrug-resistant (MDR) bacteria that have been isolated from rivers, lakes, and wastewater treatment facilities, according to studies. These bacteria pose significant threats to public health because they frequently contain resistance genes on movable genetic elements like plasmids, which can be passed on to other bacterial species. A study by Zieliński *et al.,* (2021) that was published in the Journal of Environmental Management found that wastewater-derived bacterial isolates exhibited high resistance to common antibiotics such as ampicillin, ciprofloxacin, and tetracycline. Bacteria isolated from wastewater often exhibit multi-drug resistance (MDR), posing a significant public health risk. These microorganisms develop resistance through various mechanisms such as efflux pumps, enzymatic degradation, and acquisition of resistance genes via horizontal gene transfer. In cowdung common pathogens are Clostridium difficile, *E.coli*, *Salmonella enterica, Kelbesilla pneumoniae, Prevotella melanogenica* and in soil isolates are *E.coli*, *Kebseilla pneumoniae, Salmonella enterica, Pseudomonas aeruginosa, Pseudomonas putida*. Isolates from cow-dung sample shows resistant to Beta-lactamase, Rifamycin, Tetracycline, Cephamycin and in soil it show resistant to Sulfanomide, aminoglycoside and other multi-drug classes. Out of 10 cow-dung and soil floors 9 contains at least one ARG ranked in the highest thread or risk to humans health (Anna T. Nguyen *et al.,* 2025).

E. coli was isolated from sewage treatment and antibiotics sensitivity pattern studied for 16 antibiotics it shows high resistant to AMP, CFZ, CTX, FEP, STR, NAL and CIP (Praveenkumarreddy *et al.,* 2020). In Tamil Nadu, the presence of pharmaceutical residues in wastewater—particularly from hospitals, fish farms, and rural settings—has become an increasing threat to both the environment and public health. Research carried out in districts like Tiruchirappalli and Sivaganga has identified significant levels of pharmaceutical active compounds (PhACs) in untreated hospital wastewater. Using high-performance liquid chromatography (HPLC), detected that commonly used antibiotics such as trimethoprim**,** reaching concentrations as high as 17,834 ng/L**,** and cefepime at levels up to 896 ng/L**.**

Current Stratergy to Prevent AMR

One Health Approach

The One Health cycle of antimicrobial resistance (AMR) demonstrates how resistant bacteria and resistance genes are continuously amplified and spread throughout the environment, animals, and people. When antibiotics are used extensively, as in hospitals or intensive animal husbandry, they exert selective pressure, which leads to the growth and multiplication of resistant microbes (also known as "amplification").

These resistant genes and bacteria are subsequently discharged into the environment through animal manure, wastewater, and sewage. Despite lowering the load, treatment methods frequently fail to totally eradicate AMR, allowing germs to infiltrate crops, wildlife, soils, and surface waterways.

Contaminated food, water, or direct touch can re-colonize human and animal populations. The cycle is completed and reinforced when resistant microorganisms re-enter healthcare or agricultural systems and are exposed to more antibiotics. Because of this, fighting AMR necessitates coordinated, cross-sectoral initiatives encompassing healthcare, veterinary, agriculture, waste management, and environmental research. This presents a complex, cyclical challenge with no one weak point (Elizabeth M. Parker *et al.,* 2024).

Antibiotic stewarship

To reduce AMR globally, surveillance and monitoring are crucial. Countries must address AMR surveillance data in order to respond to AMR threats before they become serious emergencies. GLASS (global Antimicrobial Resistance) is a primary data collection it's aim to strengthening the AMR evidence base and policies for AMR control. It established by WHO in 2015. It helps countries monitor and report AMR by standardized methods.

National AMR Surveillance network (NARS-NET) is the national level surveillance. In this required to submit AMR surveillance data of 9 priority bacterial pathogens such as *Staphylococcus aureus, Enterococcus species, Klebseilla sp, E.coli, Pseudomonas aeruginosa, Acinetobacter baumanii, Salmonella typhi, Salmenella paratyphi.* The main aim of this NARS-NET to monitor the patterns of drug resistance in priority pathogens it contains 40 labs and 31 states and UT.

Table.1 Antibiotics and Resistant Bacteria details

S.No	Bacteria	Resistant Antibiotics
1	*Streptococcus pneumoniae*	Penicillin, Erythromycin, Amoxicillin, Azithromycin
2	*Pseudomonas aeruginosa*	Penicillin, Aminoglycodies, Cephalosporins, Fluroquinolones, Carbapenems
3	*Acinetobacter spp*	Resistant to all antibiotic including Carbapenem
4	*Neisseria gonorrhoeae*	Pencillin,Tetracycline,Fluoroquinolones
5	*Mycobacterium tuberculosis*	Rifampicin, Isoniazid, Fluoroquinolones, Amikacin, Kanomycin, Capreomycin
6	*Enterococci faecium*	Ampicillin, Vancomycin, Penicillin, Gentamicin, Kanamycin, Tobramycin
7	*Staphylococcus aureus*	Pencillin, Methicillin, Vancomycin, Linezolid
8	*Staphylococcus epidermidis*	Methicillin, Quinolones, Vancomycin, Linezolid
9	*Listeria monocytogenes*	Tetracyclines, Fluoroquinolones low level resistant to Streptomycin, Chloramphenicol, Macrolide
10	*Salmonella enterica*	Fluoroquinolones, co-trimoxazole, ampicillin, chloramphenicol
11	*Shigella spp.*	Fluoroquinolones, co-trimoxazole, azithromycin
12	*Haemophilus influenzae*	Ampicillin, fluoroquinolones, co-trimoxazole

Indian council of medical Research (ICMR) established the AMR surveillance and research network (AMRSN) in 2013. 20 regional centers and 7 nodal centers are there this center conduct ABST Antimicrobial susceptibility test and molecular studies on resistant pathogens to identify emerging resistance trends within the country (Vijay Pal Singh *et al.,* 2024).

A program that promotes the responsible use of antibiotics is known as an antibiotic stewardship program. To guarantee that everyone who needs antibiotics has access to them, antibiotic stewardship is crucial. The ideal choice, dosage, and course of antibiotic treatment that produces the best clinical outcome for the treatment or prevention of illness with the least amount of harm to patients and the least amount of influence on future resistance is known as antibiotic stewardship. One crucial strategy for stopping the growth of drug-resistant microorganisms in hospital environments is antimicrobial stewardship.

It guarantees that patients get care when they need it and that only the appropriate medications are taken at the appropriate times. Ensuring that antibiotics are prescribed appropriately is the primary objective of ASMP in India. The National Action Plan on AMR, launched in 2017 by the Ministry of Health and Family Welfare, outlines strategic priorities including awareness, surveillance, infection prevention, and optimization of antibiotic use.

Alternative theraphy

When antibiotics have failed to treat an infection, phage therapy—which use bacteriophages to precisely target and eliminate drug-resistant bacteria—has shown promise. Furthermore, human and other organisms naturally synthesize antimicrobial peptides (AMPs), which have broad-spectrum effectiveness and the ability to break down bacterial membranes with less resistance development. Probiotics and prebiotics are also used as a preventive measures by boosting the host's natural microbiota, it also improves gut health and prevent pathogens colonization. Gene therapy, somatic therapy, and tissue-engineered medicines are the three main categories into which advanced therapy, or ATMPs, can be divided.

Recombinant genes are inserted into the body in gene therapy medications to treat conditions like cancer, chronic illnesses, and genetic problems. In order to change their bological disorders, somatic cell therapy medications affect cells or tissues. Modified cells or tissues are used in tissue-engineered medications to replace, regenerate, or repair damaged human tissue (Greta Kaspute *et al.,* 2025).

Traditional medicine

Multi-drug resistance can be addressed with plant-derived medicines by applying traditional knowledge from disciplines like Ayurveda, Traditional Chinese medicine, and ethanobotany, which is essential for finding useful medicinal plants and creating novel medications. Herbal remedies are becoming more well-known due to their effectiveness, reduced side effects, and affordability. Secondary metabolites of plants are known as plant-derived antimicrobial compounds, and their antibiotic action without causing resistance makes them extremely concerning. Numerous secondary metabolites, including alkaloids, glycosides, coumarins, steroids, saponins, tannis, and quinones, can be produced by plants. Secondary metabolites from particular plants may be able to treat and manage illnesses (Jatin Srivastava *et al.,* 2014). Antimicrobials of medicinal plant extracts are natural, safer than synthetic alternatives, available in local communities,

Author Contributions

S. Arul Jothy: Investigation, formal analysis, writing—original draft. M. Prakash, and: Validation, methodology, K. Arivazhagan: writing—reviewing; R. Sabarish: Formal analysis, writing—review and editing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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