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Indian Journal of Microbiology Research

Journal homepage: www.ijmronline.org

Review Article

From pasture to plate: Understanding antibiotic challenges in Indian livestock

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Abstract

Farm animals in India are increasingly vulnerable to antibiotic-resistant pathogens, primarily due to the routine incorporation of antibiotics into their feed. Research indicates that the excessive antibiotic use, especially in the dairy, beef cattle, poultry, and pig sectors, has led to the emergence of resistant strains of pathogens, resulting in substantial mortality and economic losses. This review highlights the Indian situation on AMR in livestock, with a focus on antibiotic abuse, the transfer of resistant genes, and legal issues concerning acquired resistance in animals. AMR spreads primarily through the food chain, such as food-borne transmission, direct contact, and environmental routes, all of which are significant health risks to public health. The review also discusses the lack of awareness among farmers about antibiotics and AMR, with most people unaware of the word antibiotic and its implications. The "One Health" approach needs to be adopted to combat this problem, fostering cooperation among human, animal, and environmental health sectors. Addressing this serious health threat through stringent legislation, proper use of antibiotics, increased awareness, and strengthened surveillance is needed to maintain animal welfare as well as public health.

Keywords: Antimicrobial resistance, Farm animals, Antibiotics, Livestock.

Received: 22-04-2025; **Accepted:** 01-06-2025; **Available Online**: 01-07-2025

1. Introduction

Livestock production plays a significant role in maintaining food security and nutritional health in India, sustaining the livelihood of many communities. India ranks among the largest consumers of antibiotics worldwide, with a total Defined daily dose (DDD) of 5,091 million used in 2019.[1] The country scuffles with a high incidence of bacterial diseases, rapid population growth, excessive antibiotic use, insufficient healthcare infrastructure, and a large livestock industry that often relies on growth promoters. Altogether, these issues contribute to the rise of multidrug-resistant (MDR) pathogens, posing a serious challenge that goes beyond defined norms or accountability.[2]

Antibiotic resistance is a significant public health risk that could expedite substantial mortality and economic implications. The transmission of these resistant species from animals to humans can be an imminent concern. AMR-related deaths now account for around 700,000 deaths annually; however, estimates suggest that number might rise to 10 million by 2050. AMR is now accountable for more deaths than cancer and road accidents combined. Economic projections suggest that by the year 2050, AMR could decrease global gross domestic product (GDP) by 2-3.5%,[3] with livestock production potentially falling by 3-8%.[4] The worldwide exacerbation of AMR has piqued the attention of the World Health Organization, and its BPPL 2024 report has emphasized the need for developing a comprehensive public health approach to address AMR.[5] In response to WHO, health authorities in various countries, including India, have implemented various action plans to address AMR. India implemented its National action plan for AMR for the period 2017-2021. Yet, awareness of antimicrobial resistance remains low in India.

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https://doi.org/10.18231/j.ijmr.2025.023

The present review intends to discuss the available Indian data on farm animals and antimicrobial resistance, emphasizing the overuse of antibiotics in veterinary services in various regions, the resistant genes involved and their transfer to humans, legal aspects, and the antimicrobial resistance acquired in various isolates derived from different farm animals, including dairy cattle, pigs, and poultry. In addition, bacterial pathogens such as *Escherichia coli, Salmonella spp., Staphylococcus aureus,* and *Campylobacter spp*. have been emphasized, and a few other bacterial species have been described briefly on their antimicrobial resistance.

2. Antibiotic usage Patterns in Animal Husbandry in Different Regions of India

2.1. Farmers knowledge of antibiotics

A widespread lack of awareness was exhibited among farmers in various regions of India regarding antibiotics and the phenomenon of antimicrobial resistance (AMR). Most dairy farmers in three arbitrary Indian cities were unfamiliar with the term "antibiotic".[6] In addition to this, a higher percentage of 88% of the dairy farmers interviewed in the study area of Krishnagiri and Kolar district of Karnataka state were unaware of antibiotic usage either on their animals or antibiotic residues in milk.[7] Smallholder dairy farmers in different parts of India had sparse knowledge of antibiotics and were mostly unfamiliar with the concept of AMR.[8] Additionally, most poultry farmers in Punjab had no knowledge of the presence of antimicrobial growth promoters (AGPs)[9] in premixed chicken feed and the associated health risks linked to antimicrobial resistance.[10,11]

2.2. Purchase of over-the-counter antibiotics and professional consultation

The pattern of antibiotic usage by farmers in India has been studied under different criteria, all of which constitute a crucial part of the treatment and healing process of diseased animals. The sale of antibiotics to farmers is often largely unregulated and unsupervised, and drugs are available without a valid prescription or with old ones.[2,6,12] In Telangana, 75% of cattle and buffalo farmers, 93.33% of sheep and goat farmers, and 68.33% of poultry farmers drew antibiotics over the counter, without prescription. Analysis of the veterinary consultancy utilization status conducted in Haryana revealed that small farmers had a low level of veterinary consultancy compared with the medium farmers (76.79%) and large farmers (87.50%).[14] Milk vendors, feed stores, and cooperatives have also been reported to be selling veterinary drugs. A general ignorance of clients about the efficacy of antibiotic use exposes them to purchasing inferior products and practicing wrong dosage measures. Since private veterinary consultations are deemed expensive by many, farmers resort to their own methods to manage disease. Those in Guwahati and Karnal use home remedies or rely on old prescriptions. Similarly, farmers in Kolkata consulted 'homeopathic' practitioners.[8] Contrastingly, animal rearers in Bangalore displayed reliance on private veterinary services and government schemes, making non-prescribed antibiotic usage rare.

2.3. Identification of antibiotics

A considerable proportion of farmers lack technical knowledge of common antibiotics or uses thereof. Many in Telangana relied on the vial (54% of cattle, 58.34% of goat and sheep farmers, and 26.67% of poultry farmers), colour of antibiotics (27% goat and sheep), or generic name (35% cattle, 55% poultry).[11] Farmers in Guwahati and Karnal could not name common antibiotics used in allopathy and administered powders, tablets, and injections based on the recommendation of a local pharmacist.[8] Farmers show preference towards drugs that exhibit rapid results, are readily available, and have worked in their previous experience[1] Of all farmers in Haryana and Assam, only 11% were able to recognize picture cards of seven famous antibiotics. However, there was no relation between being able to recognize antibiotics and knowledge of the same. Of the farmers who identified antibiotic picture cards, 47% later stated that they had never heard of antibiotics.[16] They all eventually culminate in misuse of antibiotics, which is one of the factors that fuels AMR in livestock.

2.4. Verification of antibiotic viability

Around 63% of farmers in Telangana,[11] do not verify expiry dates before giving antibiotics to animals or birds. Specifically per category, only 26 percent of the cattle and buffalo producers and 18.33 percent of the sheep and goat producers said they ever read expiry dates on the antibiotics they administer to their animals. But about antibiotic use, it was seen that 63.33% of poultry farmers declare they occasionally search for expiration dates.

2.5. Full course of antibiotic regimen

Farmers in Rajasthan and Telangana admitted to administering antibiotics just until disease symptoms alleviated. In rare instances, they continued the full course of antibiotics.[11,17] Some of the priority factors that were in this decision were the appearance of recovery signs, increased financial cost, time constraints, ineffective antibiotics, and side effects. A significant portion of cattle and buffalo farmers in Telangana (45%) never pursue follow-up treatment[11] after antibiotic therapy, while 37% occasionally do, and only 18.34% consistently adhere to it. Among sheep and goat farmers, just 15% fully follow through; 42% do so sometimes, and 44% skip follow-up altogether. Contrastingly, 78% of poultry farmers engage in follow-up treatments at varying intervals, leaving only 21% that do not. Higher adherence in poultry farming could be a function of better information provided by animal health service providers about the importance of follow-up treatments, a practice that appears less common in other livestock sectors.

2.6. Withdrawal period

Withdrawal time, or withdrawal period, of antimicrobials refers to the interval between the last dose of antimicrobial administered to the animal and the interval in which the residue level in the tissues (muscle, liver, kidney, skin/fat) or products (milk, eggs, and meat) is less than or equal to the Maximum Residue Limit (MRL). This is achieved in a bid to prevent unauthorized use of antimicrobials by humans through the food chain.[18] Among farmers surveyed regarding withdrawal periods, 20% in Telangana recognized the need, but only 10% complied with it after using antibiotics. In Rajasthan, young and educated people were more active than older or less-educated ones. Non-compliance usually resulted from fear of financial losses, lack of extension services, poor regulations, or ambiguous instructions from authorities. Most dairy and poultry farmers who were not aware of withdrawal regulations kept selling eggs and meat during and after the use of antibiotics. Surprisingly, some farmers in Karnal and Bangalore boiled milk even though they were aware of the health hazards of antibiotic residues. Even farmers who knew about withdrawal periods mentioned wastage issues and continued consuming the milk. Farmers in Kolkata circumvented regulations by selling such milk door-to-door. Guwahati consumers spurned milk only when discolored, Karnal consumers when it had poor consistency or stench, whereas in Bangalore and Kolkata, milk was rejected only when it was curdled or gone bad.

3. AMR in Dairy and Beef Cattle

3.1. Antibiotic use in the production of dairy and beef

Cattle from traditional dairies seem to retain antimicrobial-resistant bacteria comparatively higher than that of organic dairies.[19] The use of antibiotics in rearing cattle leads to the selection of resistant strains, not only in terms of animal health risk but also in human health through the food chain, thereby making antimicrobial resistance an area of concern in the cattle industry.[20] Some of the commonly used antibiotics and the resistant genes associated has been provided in **Table 1**. Horizontal gene transfer among the bacteriophages of the bacterial population infecting cattle also plays a major role in the mechanisms of resistance development, whereby resistance genes are exchanged speedily between bacteria.[21]

3.2. Antimicrobial resistance prevalence in dairy and beef cattle

Cattle have been found to harbor resistant forms of pathogens, including *Salmonella* and *Escherichia coli*, which present significant concerns. Milk and meat are essential in human diets but are prone to bacterial contamination such as *E. coli* Humans can become infected with resistant bacteria from cattle.[27,28] Brucellosis has been found to affect livestock productivity and cause illness in humans. High Brucella seroprevalence is found in Haryana farms, and there is a call for control programs to improve health.[29] Research has indicated that farms that practice poor cleanliness and antibiotic stewardship have higher rates of antimicrobial resistance (AMR).[30]

3.3. The effects of AMR on productivity in cattle and public health

The use of antibiotics in dairy farming, if not managed properly, can leave harmful residues in milk and meat. In India, dairy farmers use antibiotics frequently to treat diseases like udder infections in cattle. Due to easy availability, antibiotics meant for humans are also used in animals. The widespread antibiotic use has contributed to higher levels of antibiotic-resistant bacteria in humans in India.[31] Resistant bacteria spread through the food chain, which poses significant public health risks.[32] Antimicrobial Stewardship (AMS) promotes accountable use of antibiotics to reduce drug resistance, minimizing the impact of antibiotic overuse.[33]

Table 1: Commonly used antibiotics in cattle farming and associated resistance

Antibiotic	Purpose of Use	Bacteria Targeted	Associated Resistant Strains	References
Tetracycline	Growth promotion, Infection control	*E.coli, Salmonella*	*E.coli* (Tetracycline resistant)	22
Penicillin	Mastitis treatment	*Staphylococcus aureus, Streptococcus*	*Staphylococcus aureus* (MRSA)	22,23
Cephalosporins	Broad-spectrum bacterial infections	*E.coli, Salmonella*	*Salmonella* (Cephalosporin-resistant strains)	24
Sulfonamides	Respiratory and gastrointestinal infections	*Pasteurella, E.coli*	*Salmonella* (Sulfonamide-resistant)	24,25
Fluoroquinolones	Enteric infections, respiratory disease	*Campylobacter, Salmonella*	*Campylobacter* (fluoroquinolone-resistant)	26

Table 2: Resistance profile of the bacteria (*E. coli, Salmonella, Staphylococcus, Streptococcus*) isolated from various pig samples

Reference	Region	Organism	Sample Isolated from	Resistant antibiotic
39	Uttar Pradesh Tamil Nadu Karnataka	*E. coli*	Faecal samples	Cefodaxime (100%)
41	Arunachal Pradesh	*E. coli*	Faecal samples	Imipenem (99.61%)
42	North India South India North eastern India	*E. coli*	Faecal samples	Amoxicillin (92.1%)
43	North eastern India	*Staphylococcus*	Nasal swabs Vaginal swab Skin swabs	Ampicillin Penicillin
44	Mizoram	*Salmonella*	Faecal specimens	Cefotaxime (80%)
45	Northeast India	*Streptococcus*	Nasal swabs	Tetracycline (88.46%)

4. AMR in poultry

India, being a populated nation with a population of over 1.4 billion people, flourishes its poultry industry and is one of the emerging agricultural sectors. India stands third in the largest egg production and nineteenth in the largest broiler production in the world. The five topmost poultry-producing states are Maharashtra, Uttar Pradesh, West Bengal, Andhra Pradesh, and Telangana. Among animal-sourced foods, eggs and chicken are the most consumed due to their nutrition and economy compared to other animal source foods. The widespread proliferation of antimicrobial resistant microbes in poultry has become endemic as a result of irrational antimicrobial usage.[34] Failure to complete the course of antibiotics and use of suboptimal doses of antibiotics and extensive drug treatment can be some of the major causes of the spread of antibiotic-resistant microorganisms.[11]

4.1. Broad application of antibiotic usage in poultry

E. coli produces intestinal and extraintestinal infections in both humans and animals. It is one of the crucial factors in financial losses resulting from diseases in commercial poultry farms and increasing mortality. A study conducted in Meerut from January to April 2020 showed that the overall prevalence of *E. coli* is 54%. The disc diffusion method against various antibacterial drugs indicated a 100% resistance level against Cefotaxime, followed by Enrofloxacin at (89%), Doxycycline hydrochloride at (85%), tetracycline at (70%), Ciprofloxacin at (52%), chloramphenicol, and ampicillin at (44%). The high susceptibility shows against gentamicin at (100%), followed by streptomycin at (96%), ampicillin at (41%), ofloxacin, and chloramphenicol at (33%), while the normal susceptibility rate indicates ciprofloxacin at (15%). The indiscriminate use of these drugs leads to higher drug resistance against antibacterial isolates. In order to control the increase of antibiotic-resistant microorganisms, the consumption of antibiotics should be decreased.[35]

4.2. Antibiotic Resistance towards bacteria

Staphylococcus spp. and S. aureus were isolated from chicken eggshells at 20.45% and 10.45%, respectively. Staphylococcus spp. was most frequently isolated from cases of chest infections. On quail eggshells, S. aureus and Staphylococcus spp. were isolated at 5% and 16.25%, respectively.[37] Out of the seven isolates studied, four were found to be positive for the nuc gene using PCR, which gave a 57% positivity rate. The mecA gene was identified in three isolates (15%). Six isolates were found to be oxacillin-resistant Staphylococcus aureus. Antibiogram study showed that most of the isolates were resistant to β-lactam antibiotics.[38]

5. AMR in Pig Breeding

Pig breeding in India contributes around 1.7% of the total livestock of the country. About 292.5 thousand metric tons of pork were consumed in India in 2023. While the country struggles to improve its production of meat in order to meet the increasing demands of a developing population, implications of AMR on animal health, particularly pig production, have to be wisely considered. Due to their greater importance and occurrence in pig breeding, most antimicrobial resistance data on isolates obtained from swine produced in India refer to three main microorganisms: *E. coli*, *Staphylococcus*, *Salmonella*, and *Streptococcus* (**Table 2**).

5.1. The extensive use of antibiotics in pig production

The use of antibiotics was found to be greater in swines for mastitis (47–67%), then for diseases like fever (18%) and reproductive issues (15%) among animals. Compared to nutritional supplements (14–16%), antihistamines (17%), and anti-inflammatory drugs (20%), the most frequently utilized category of medicines was antibiotics (23-28%). Mastitis was the leading reason for the use of antibiotics (47–67%) relative to fever (18%), reproductive diseases (15%), and lameness (16%).[46] Antibiotics are given prophylactically and used as growth promoters, mainly in pigs, to enhance livestock performance. The practice is, however, a serious public health threat because of the increased emergence of antibiotic-resistant bacteria, which is spread along the food chain.

5.2. Resistivity of the bacteria towards antibiotics

A cross-sectional study carried out in 2016-2017 reported that 42.9% of the isolates from pig farm workers and 44.4% of the isolates from piglets were ESBL positive.[47] The ESBL producers were 100% resistant to cefotaxime, cefpodoxime, cefoxitin, ceftazidime.[39] The PCR analysis of *S. aureus* isolates resulted in 94% of them showing the presence of the mecA gene, making them resistant to tetracycline, penicillin, and clindamycin.[48] The treatments for streptococcal infections fail due to the enhanced resistance to the antibiotic drugs.[49] A relatively high percentage of the isolates of *Streptococcus suis* (20–39%) was even clinically found in the healthy pigs. Although scanty results were available from India, an investigation from all the north-eastern states of India revealed the resistance of *Streptococcus suis* to TET, clindamycin, co-trimoxazole, and erythromycin.[50]

5.3. Effects of prolonged antibiotic usage in pigs

The consequences of AMR are profound and multifaceted. The infections by resistant bacteria result in increased morbidity and mortality in pig populations, resulting in significant economic loss. Antibiotics can also lead to several adverse health effects in humans.[51] Allergic reactions to penicillin and other classes like aminoglycosides and tetracyclines are prevalent. While β-lactams were once considered less toxic, they are now associated with a significant number of allergic reactions. Additionally, low levels of antibiotic residues in meat, milk, and eggs contribute to antibiotic resistance in microorganisms. Also, most of the studies have shown the spread of antibiotic-resistant genes through the pig gut microbiome into the environment and even to humans through the food chain.[52] The long-term implications for human health as a result of long-term use of such antibiotics are also not known and call for more research in the drug industry and regulation in their application.

6. AMR Organisms within farm Animals in India

6.1. Escherichia coli

E. coli are commensal bacteria that have serious public health effects and are resistant. Extended-spectrum β-lactamases (ESBLs), which are principally produced by *E. coli* of the Enterobacteriaceae, impart resistance to the majority of β-lactam antibiotics employed in human and veterinary medicine. In the last few years, the sudden onset and dissemination of ESBL-positive *E. coli* among food animals were of international concern as they can pass on through the food chain.[42]

E. coli causing extraintestinal infections in domestic poultry is termed avian pathogenic *E. coli* (APEC). In the study, 102 samples from chickens that died of colibacillosis revealed the presence of ESBL-producing APEC strains carrying genes like *blaTEM*, *blaCTX-M9*, *blaSHV*, and *blaOXA*. Most isolates had virulence genes such as *iss* and *tsh*. The presence of class I integrons encoding both ESBLs and virulence markers makes these isolates zoonotic, posing a serious public health risk via food or environmental transmission.[53]

A 2024 study on *E. coli* from chicken cloacal samples across six zones of West Bengal revealed high antimicrobial resistance (AMR) in isolates from the aged alluvial zones, with ampicillin resistance widespread—except in red and laterite zones, where resistance was minimal. Agroclimatic factors influence bacterial physiology, genetics, and AMR traits. Temperature impacts growth, bloodstream infection risk, and gene transfer, while pH affects bacterial homeostasis and resistance profiles. Biofilms—bacterial communities enclosed in secreted substances—contribute to virulence and AMR. Genes like *crl*, *csgA*, *fimH*, *luxS*, and *papC* are involved in attachment and infection. However, the study noted that biofilm gene presence doesn't guarantee biofilm formation—it depends on gene expression levels.[54]

A north-east Indian study cultured 42 multi-drug resistant (MDR) E. coli strains from pig farms. The antibiogram tested resistance to at least 6 and up to 23 antibiotics with higher resistance to amikacin. In another research in Mizoram, where pig farming is predominant, pig fecal sample isolates of E. coli showed high gentamicin, amoxicillin, co-trimoxazole, SF, tetracyclines, and trimethoprim resistance.[55] The antimicrobial resistant profiling of the isolates from *E. coli* from the North East Indian pig farms resulted in the highest level of resistance to ampicillin, followed by amoxycillin and cefalexin (79.97%).[56] Conversely, the isolates were susceptible to ceftriaxone and ciprofloxacin. Streptomycin, cefotaxime, aztreonam, and ceftazidime. In the research on the antibiogram pattern of AMR *E. coli*,[57] they reported the presence of ESBL-producing *E. coli* in water, feed samples, and even boot sock dust. Water samples had the highest amount of multidrug-resistant bacteria, followed by feed samples.[57] The identification and characterisation of MDR *E. coli* in Arunachal Pradesh, revealed that the isolates were positive for blaTEM, blaCTX-M, blaCMY, and blaSHV genes, respectively. These genes code for ESBLs and allow the spread of resistant genes to other organisms.

6.2. Staphylococcus aureus

Staphylococci are Gram-positive coccus bacteria which grow in clusters, causing a wide range of diseases from superficial to lethal in animals. *Staphylococci* are opportunistic pathogens and are able to cause nosocomial infection in animals as well as in humans. They cause osteomyelitis, synovitis, and cellulitis in poultry. Diseases in poultry range from dermatitis to systemic disease. Exudative dermatitis in swine is caused by *Staphylococcus*.[43] Pigs show the highest incidence of mecA gene amongst poultry and bovine. Methicillin-resistant *Staphylococcus aureus* (MRSA) emerging from swine, having an incidence rate of 41% of MRSA human infection in India, poses a huge issue.[58] The MRSA strain usually carries the mecA gene, which codes for the PBP 2a penicillin-binding protein, making it resistant to methicillin, penicillin, and other penicillin-type drugs.[59] In addition, MRSA is one of the most commonly isolated etiological agents for porcine mastitis, and the responsible gene is found to be the mecC gene, and it was first isolated from pigs.[22]

The research revealed that *Staphylococcus aureus* from poultry litter is plasmid-coded and multi-drug resistant. Antibiotic-resistant bacteria are spread from the environment to other biospheres, affecting humans. Horizontal gene transfer by plasmids makes this resistance difficult to treat. Vancomycin resistance at high levels, the last treatment option for staphylococcal infection, makes control even harder. To avoid human endangerment, the application of antibiotics in profit poultry farming needs to be regulated.[60]

Staphylococcus spp. has been recognized as a leading multidrug-resistant bacterium because it is resistant to many antibiotics. A study indicates that *Staphylococcus spp.* has progressively developed resistance to tetracycline (100%) and benzylpenicillin (33.3%). It has also become resistant to third-generation beta-lactamase antibiotics. Of the isolates, 63% were tetracycline-resistant, and 33.3% were erythromycin- and clindamycin-resistant.[61]

The research examined *Staphylococcus aureus* in subclinically mastitic cows, enterotoxin genes, and antimicrobial resistance patterns. Out of 180 cows, 78 (46.99%) exhibited subclinical mastitis, and three buffalo (21.43%) were infected. Clinical mastitis was minimal at 3.61%. S. aureus were isolated from mastitic milk and udder swabs, with 52 confirmed strains, of which 17 produced enterotoxins. The strains exhibited high resistance to penicillin and oxacillin. This research forms the basis of tracking antibiotic resistance in bovine mastitis in India.[62]

Dairy cattle mastitis is a real problem in dairy farming. While working on research in Haryana, 675 raw samples showed 14.37% subclinical and 11.25% clinical mastitis. Twenty-nine samples showed antibiotic residues by analysing 79 samples, including *E. coli* (18.49%) and *S. aureus* (38.72%) being resistant to antibiotics. Among the most prevalent drugs such as ampicillin and penicillin-G, high rates of resistance have been reported. Misuse of antibiotics among untrained health professionals, and the lack of diagnostic equipment, are some of the causes of increasing antimicrobial resistance, further requiring ongoing screening.[63]

6.3. Salmonella spp

Salmonella is a leading causative agent of foodborne illness in humans and animals. Asymptomatic carriers and a risk factor for contamination during slaughter are pigs. Multidrug resistance in pigs has been prompted by extensive use of antibiotics in pig production. Salmonella from Mizoram pigs was highly resistant to ceftriaxone (80%), ceftazidime (80%), cefotaxime (70%), cefixime (70%), gentamicin (70%), ampicillin (60%), and cotrimoxazole (60%).[44] Similarly, in a study conducted in the region of Assam and Meghalaya, it was found that about 60% of the isolates from the faecal sample were confirmed as ESBL producers.[64] In another study conducted in the state of Karnataka,[65] the *Salmonella* isolates exhibited resistance to tetracycline, ampicillin, streptomycin, cefotaxime, and ceftriaxone. Approximately 18.2% of the isolates had a multiple antimicrobial resistance (MAR) index score ranging from 0.56 to 0.67. The study also detected virulence genes, including invA, spvR, spvC, and stn, from *S. weltevreden* and *S. enteritidis*. Another investigation on *Salmonella* isolates from pigs found resistance to gentamicin.

Salmonellosis is a major zoonotic disease, threatening public health and causing significant economic costs. The rising antimicrobial resistance in *Salmonella* strains is a growing global concern.[66]

This research revealed that Salmonella isolates were highly resistant to antibiotics: 100% to doxycycline, 97.62% to oxytetracycline, 88.10% to neomycin, and 83.33% to erythromycin. These resistant isolates can transfer resistance genes to highly virulent gram-negative bacteria in poultry.[67]

The common serovars identified were *Salmonella typhimurium* and *Salmonella enteritidis*, linked to foodborne illness. They show resistance to antibiotics like ampicillin and tetracycline, which exhibit multi-drug resistance. These isolates carry virulence genes such as invA and spvC, indicating pathogenic potential. There is a high risk of transmission from poultry to humans, necessitating improved food safety practices.[68]

The study isolated the strain SMC25 from poultry meat, confirming its presence in the food supply chain. They exhibited resistance to several antibiotics, such as ampicillin, chloramphenicol, and tetracycline, which is a significant threat. SMC25 showed high biofilm-forming ability, which increases its persistence in food and makes it virulent. Molecular analysis showed the presence of virulence genes like invA and sipB, which connect the strain to human pathogenicity.[69]

The *Salmonella* species, particularly *Salmonella Typhimurium*, pose a threat to the gastrointestinal diseases of dairy cattle and the overall health of the herd. These pathogens employ a range of virulence factors, the primary mechanism of which is secretion by a type three secretion system (T3SS), where they invade into epithelial cells and persist within phagocytic cells. This class adheres to the animal model of cattle. Besides, there are other host factors, like the natural resistance-associated macrophage protein 1 (Nramp1), that influences susceptibility to Salmonella infections; this indicates a two-way interaction on both pathogen and host levels controlling disease dynamics.[70]

6.4. Streptococcus spp

Streptococcus strains are referred to as biofilm producers due to enhanced resistance of their biofilms to antibiotics. *Streptococcus suis* is among the major causative bacteria in the swine sector globally.[71] *Streptococcus suis* is a gram-positive in antigenic properties of their capsular polysaccharides. In another study from Northeast India, the encapsulated cocci with almost 30 recognized serotypes, which are identified by differences, reported a high frequency of resistance to antimicrobials like co-trimoxazole, clindamycin, tetracycline, and erythromycin.[45] From the study, it was also noted that 88.46% of the isolates were multidrug resistant, and the most common gene was the arcA gene, responsible for its virulence in swine.

6.5. Enterococcus spp

Enterococcus is a gram-positive, family *Enterococcaceae* bacterium. Enterococci are among the predominant colonizers of human and animal intestines. They are also the causative agents of locomotive disease and broiler septicemia. Emergence of multidrug-resistant (MDR) and drug-resistant *Enterococci* in poultry is of specific public health significance due to the fact that such strains cannot be cured using effective medicines and can spread the resistant genes to other pathogens, apart from being transmissible from poultry to human beings. This has resulted in the development of infections by multidrug-resistant *Enterococci* that are not only hard to manage but also have high mortality.[72]

There was a high resistance rate among the isolated enterococci, with most of them being tetracycline resistant, the study revealed. The study identified the presence of tetracycline resistance genes (tetM and tetL) in 78% and 68% of isolates, respectively, while tetA and tetB genes were present in 2% of isolates. Phenotypic erythromycin and ampicillin resistance were found in 31.1% and 30% of isolates, respectively. Production of biofilm was noted in 81.1% of the isolates here. Even biofilm production has been associated with antibiotic resistance among *enterococci*.[37]

6.6. Campylobacter

The study demonstrated the prevalence and diversity of thermophilic Campylobacter species, particularly *Campylobacter jejuni*, in dairy cattle herds. It was determined that 23% of animals were positive and 83% of farms were positive for *C. jejuni*. Generally, calves had higher prevalence and concentration levels of Campylobacter than the older ones. That is, there was a suggestion that some serotypes were apparently better than others at transmission or colonization. Results indicated that cattle are a significant reservoir of *C. jejuni* and may serve as a potential source of infection to man through zoonotic transmission.[73]

7. How AMR from Animals is transferred to Humans

Antimicrobial resistance represents a serious threat to international public health by impairing the potency of antibiotics as well as other antimicrobial drugs. One considerable channel for the spread is through industrial animal agricultural practices. The concern is ever-growing over the transfer of antibiotic resistance from animals to humans, predominantly due to use of antibiotics in large-scale production as a preventative measure.[74] Eighty percent of all manufactured antibiotics that are being sold in the United States are used as agents for preventing disease and as growth promoters in cattle. In China and Japan, the same is around 52% and 50%, respectively.

Livestock production employs antibiotics at an excessive level to enhance growth and prevent sickness in the animals. Such an approach may promote the dissemination of antimicrobial-resistant bacteria within animal populations. These resistant bacteria can subsequently penetrate the environment via multiple pathways, including manure and runoff, eventually reaching the human population.

There are three major sources of resistance in the cultivation of farm animals. These include commensals, soils, and the farm animals themselves.

7.1. Commensals

Commensals are microorganisms that normally live in the body without harming and often have a mutualistic association with the host. Such organisms are part of the normal flora, for example, bacteria residing in the gut, skin, or mucous membranes. Commensal bacteria may host and share antimicrobial resistance genes. These are capable of being passed to pathogenic bacteria, widening the pool of resistant pathogens that may produce infections. Several of these bacteria have been shown through research to contain homologues of resistance genes from associated pathogenic bacteria. Whether or not gene flow from commensals to the pathogen happens is still questionable.[75]

7.2. Soil

There exists a common resistome among the soil bacteria and pathogenic humans that indicates that the soil microbiota is a reservoir of resistance genes. Horizontal gene transfer can enable this exchange; these systems provide mechanisms whereby the bacteria transfer genes, including antibiotic resistance genes. ARGs allow transmission between and within species. It drives the evolution of mobile genetic elements, e.g., plasmids carrying multiple antibiotic resistance genes, leading to multidrug resistance and ubiquitous drug-resistant bacteria; these plasmids can be transferred between a variety of species of bacteria within various environments.

7.3. Farm animals

Industrial production of livestock heavily relies on its usage of antimicrobial agents to improve animal health and yield. They are mainly used for i) growth promotion, ii) disease prevention, iii) lack of regulation in antibiotic use, and iv) low cost and easy access. Farm workers and veterinarians who are in direct contact with livestock can be exposed to a large amount of bacteria that are present in the environment around the animals (e.g., water, soil, feed). Transmission of the microbes such as Escherichia coli, Salmonella, and Campylobacter can occur through open wounds, respiratory tract, and hand-to-mucosal zone contact. A study conducted in 2021.[76] identified the genetic relatedness of multidrug-resistant *E. coli,* which were isolated from humans and poultry environments. Among the 110 strains, 42.7% were sourced from humans, 37.7% from hens, and 24.5% were derived from the poultry environment. Antibiotics that were significantly suppressed were tetracycline, streptomycin, ampicillin, and gentamicin. These findings evaluate the widespread prevalence of MDR *E. coli* in humans who are working in poultry environments. This suggests strong proof for the dangers faced by farmers through the transmission from the poultry produce, chickens, and their surroundings.

8. Legal Aspects

India, being the fourth largest user of antimicrobials, it is of utmost importance to regulate the usage of antibiotics in farm animals. Antibiotics serve as growth promoters that are important for poultry as well as cattle. Antibiotic usage limitations are a must with the ever-growing threat of AMR diseases. Several studies have proven a relationship between antibiotic residues in the food chain and excessive use of antibiotics, which can serve as an indicator for the importance of regulation.

The National Policy on Containment of AMR and The Bureau of Indian Standards of Poultry Feed emphasised antibiotic use and AMR surveillance; however, proper regulations did not start till 2013.[77] Around 2013 came the first official regulation of medicine used for growing farm animals by the Drug Controller General of India (DCGI). Antibiotics must mention the withdrawal periods in their labels, and if not, they must be set to at least 7 days for milk and eggs and 28 days for poultry. The Department of Animal Husbandry, Dairying, and Fisheries (DAHDF) suggested regulation on the use of antibiotics on animals and monitoring it while supporting judicious use of antibiotics in animal feed by veterinarians.

The crucial controller within the Ministry of Health and Family Welfare for establishing standards in food production and quality is the Food Safety and Standards Authority of India (FSSAI). The FSSAI-published Food Safety and Standards (Contaminants, Toxins, and Residues) Regulations, 2011, were later revised during the year 2017 which set the tolerance level of antibiotics and other pharmacologically active substances in food animals and products. Some of the antibiotics that have been restricted from usage are Nitrofurans, Chloramphenicol, Sulfamethoxazole, Chloroform, Ronidazole, and more.(**Table 3**)

Table 3: Tolerance limits of antibiotics for seafood from food safety and standards (Contaminants, Toxins and Residues) Regulations (2011) (Food Safety and standards regulations, 2011)

S. No	Name of Antibiotics	Tolerance limit mg/kg (ppm)
1	Tetracycline	0.1
2	Oxytetracycline	0.1
3	Trimethoprim	0.05
4	Oxolinic acid	0.3

Six key strategies were brought forth by the National Action Plan on AMR (2017-2021) (NAP-AMR). These are the creation of improved awareness and AMR comprehension through the provision of training, infection incidence reduction, education enhancement, investment promotion, and enhancing India's leadership in AMR. Colistin, a “last resort” drug used against multidrug-resistant superbugs, was banned after indiscriminate usage as a growth promoter apart from its need for intestinal infections in poultry. Colistin had already gained attention for its neurotoxicity and nephrotoxicity in humans; hence came its last resort uses for gram-negative, carbapenem-resistant bacterial infections.[78] The ban took place with the advice of NAP-AMR and the Drugs Technical Advisory Board of India. Colistin manufacturing and distribution was also barred by the Ministry of Health. This ban, by far, is not linked with any specific regulatory body of India. Even post-these policies, the usage of antibiotics in farm animals remained largely unregulated. In 2017, a project was initiated as a joint project of the Indian Council of Agricultural Research (ICAR) and the Indian Council of Medical Research (ICMR). The underlying goal of the project was to identify gaps and to create standard operating procedures for antibiotic susceptibility testing. At a conference hosted by ICMR in 2017, it was stated that antibiotics can and cannot be exclusively reserved for animals; this covered the use of critical antibiotics such as penicillin, tetracyclines, cephalosporins, quinolones, sulfonamides, and aminoglycosides in the treatment of livestock. The Global Antibiotic Resistance Partnership (GARP), established in 2009, tried to introduce policies on AMR transmission and surveillance.[79] There is still, however, no proper surveillance system in India for antibiotic usage in farm animals. Some significant challenges can be summed up as:

1. Low awareness among farmers regarding the antibiotic usage, resistance and the potential hazards in food-producing animals.

2. Lack of appropriate regulation and monitoring of the use of antibiotics in livestock.
3. No regulatory body to solely oversee and regulate antibiotic usage in farms.
4. Insufficient localized research on antibiotic use in India.

9. Conclusion

The existence of AMR in farm animals in India poses a multifaceted problem in agriculture as well as a type of disease that affects human health and governmental policies. This review shows the difference in antibiotic use in different areas based on farmers using it on cattle, how they get infected, and how it can transfer to humans. *Escherichia coli* is the most common isolated pathogen in the rectal swabs, and is highly resistant to antibiotics in dairy and beef cattle as antibiotics are used universally for growth and prevention of diseases. Similarly, in poultry and pig breeding, for instance, the use of antibiotics not only threatens animal life but also human lives by passing through the food chain and other environmental parameters. The spread of resistant pathogens from animals to humans is the significance of the one health idea that focuses on the coordination among human, animal, and environmental health. The use of antibiotics as animal feed continues to be a legal grey area, and enforcing it is an uphill task. The systematic strategy of AMR management can be taken as a significant prerequisite to solve this issue: enhancing the stringency of legislation and encouraging the rational use of antibiotics. This means that many parties should come on board with the farmers, veterinarians, policymakers, and public health workers to ensure that measures are put in place in a way that is sustainable to the welfare of animals and humans.

Thus, it is clear that in order to tackle AMR in farm animals in India, nearly all these mentioned points need to be managed and tackled properly. In aspects such as the World Health Organisation, Nutrition for Health and Food Safety, and Improved Agricultural Productivity, there are numerous ways India can make improvements to eliminate AMR and raise the health bar for future generations to come in using antibiotics for agricultural activities.

10. Abbreviations

AMR: Antimicrobial resistance; MDR: Multi Drug Resistance; PCR: Polymerase Chain Reaction; ESBL: Extended-spectrum β-lactamases; MRSA: Methicillin-resistant Staphylococcus aureus.

11. Source of Funding

None.

12. Conflict of Interest

None.

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Cite this article: Baiju SK, Yadava I, Suriyanarayanan M, Srimathy G, Muthuswamy V, Anandan RK, Swaminathan P. From pasture to plate: Understanding antibiotic challenges in Indian livestock. *Indian J Microbiol Res*. 2025;12(2):161–171.