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A mini-review on the burden of antimicrobial resistance and its regulation across one health sectors in India

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ABSTRACT

Antimicrobial resistance (AMR) is a compelling health problem worldwide in the twenty-first century. The initiation and spread of drug-resistant pathogens pose a substantial threat to human health. Mounting evidence indicates the widespread prevalence of AMR in India. This concerning trend can be primarily attributed to the lack of effective implementation of regulations and oversight measures by regulatory bodies in multiple sectors, including humans, animals, food, and the environment. In addition, inadequate communication and coordination between these sectors further exacerbate the AMR problem. Given the current threat of AMR, it is imperative to develop and implement a robust mechanism that should work in tandem with each other to prevent the development of antimicrobial resistance, as it ultimately affects citizens' quality of life and imposes an economic burden on the country. This article aims to highlight the efforts of various organizations in India to mitigate AMR and provide recommendations for tackling emerging AMR.

1. Introduction

The discovery of antibiotics in 1928 and their commercial use around the 1940s changed society and daily life by enabling the control of infectious disease threats [1]. Antibiotics are vital therapeutic agents for treating bacterial diseases [2] and are essential for facilitating life-saving medical interventions such as organ transplants, surgeries, and treatment of autoimmune diseases and cancer [3]. It is important to note that antibiotics are not limited to human use; they are also administered to animals, such as pets, livestock, wildlife, and aquatic animals to combat infectious diseases. However, the development of antibiotic resistance, a natural occurrence accelerated by antibiotic exposure [4], has rendered several once-effective antibiotics, antifungals, and other therapies ineffective owing to the emergence of resistant microorganisms [5]. The increase in antibiotic resistance has severe consequences, including loss of life. In 2019 alone, worldwide 1.27 million deaths were directly caused by AMR, surpassing the toll of HIV and Malaria combined [6]. Alarmingly, by 2050, Asia is predicted to experience 4.7 million deaths directly by AMR [7]. India possesses one of the world's highest antimicrobial resistance rates [8]. Additionally, it also shares 3.54 % of its GDP to health expenditure, with a substantial 62.67 % being attributed to out-of-pocket expenses within the overall health expenditure (72.8 USD), as per 2018 data [9]. Given the combination of high AMR rates and a substantial out-of-pocket expenditure among the populace in India, it is anticipated that their impact on the expected global GDP reduction of USD 100–210 trillion by 2050 could be noteworthy [10].

Multiple studies have reported an increase in antibiotic consumption among humans in India [11,12], with Antimicrobial Consumption (AMC) being the primary driver of AMR. Recent data from 2019 revealed that humans consumed a total of 5071 million Daily Defined Doses (DDD), with "Watch category" drugs accounting for 54.9 % of DDDs, and "Access category" drugs accounting for 27.0 % [13]. With the escalating growth of AMC, the resistance to last-resort antibiotics such as carbapenems, among microbes has witnessed a corresponding increase. Surveillance data from the Indian Council of Medical Research (ICMR) and the National Centre for Disease Control (NCDC) also confirm the escalating rates of AMR in common infectious pathogens, such as E. coli,

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S. aureus, and others [14,15].

Animal husbandry plays a significant role in India's economy, with the agriculture and animal husbandry sector employing over 70 % of the country's population [16]. With a livestock population of 536.76 million [17], India is the largest milk producer, producing 221.06 million tonnes of milk, 129.60 billion eggs, and 9.29 million tonnes of meat annually, along with 33.13 million kg of wool [18]. However, growing demand has led to the use of antibiotics as growth promoters by farmers [19,20]. Numerous studies have detected antibiotic residues in animal-sourced foods (Fig. 1) and identified antibiotic-resistant microbes, highlighting the growing burden of AMR.

Given the widespread emergence of AMR, it is crucial to acknowledge the often-overlooked role of the environment. Of the 2152 studies published by Indian institutions on AMR, a significant majority focused on humans (48.3 %), while a mere fraction addressed animal-related aspects (3.3 %) and the environment (4.2 %) [8]. The environmental Soil and Water bodies are the major sink areas of antibiotic residue accumulation through various human activities [21]. Evidence indicates that wastewater, contaminated soil, and other environmental areas harboring antibiotic residues may contribute to AMR spread [22–24]. This connection greatly emphasizes the need to address the environmental aspects of growing AMR.

Challenging factors that contribute to the AMR burden in India include a high prevalence of infectious diseases, incompatible infection prevention control (IPC) practices, a stretched public health system, easy access to antibiotics without prescriptions (In 2010, India was the largest user of antimicrobials among the BRICS (Brazil, Russia, India, and China) countries) [11], insufficient standardized effective surveillance platforms to track drug-resistant patterns and consumption, insufficient knowledge and awareness, and limited laboratory resources for disease-based diagnosis [25].

The objective of our review highlight the different major sectoral efforts in characterizing the AMR burden in India. It provides an overview of the regulatory framework governing antibiotic use and its surveillance in each sector (Human, Animal, Food, and Environment). It also emphasizes the need to adopt the One Health idea that embraces closer interactions between stakeholders involved in the human, animal, and environmental health sectors to mitigate AMR.

2. AMR burden and regulations across one health sector in India

2.1. Human health

2.1.1. AMR surveillance

India has implemented extensive surveillance systems to monitor the AMR. The Indian Council of Medical Research (ICMR) established the AMR Surveillance and Research Network (AMRSN) in 2013, which included 20 regional centers and seven nodal centers. These centers conduct antimicrobial susceptibility tests (ABST) and molecular studies on resistant pathogens to identify emerging resistance trends within the country [14]. In line with the AMRSN, the National Centre for Disease Control (NCDC) established the National AMR Surveillance Network (NARS-net) as part of the National Program on the containment of antimicrobial resistance. Presently, this network comprises 40 laboratories in 31 states and union territories with a focus on assessing the prevalence of antibiotic resistance in India and plays a vital role in understanding the extent and dynamics of AMR [15].

Both ICMR and NCDC surveillance systems focus on priority pathogen groups that cause human infections and exhibit high rates of antibiotic resistance. These systems provide valuable evidence of the increasing burden of AMR.

Over the past year, surveillance data has highlighted concerning trends in antibiotic resistance among prevalent pathogens. Specifically, E. coli's susceptibility to antibiotics has been severely compromised, with only 18.1 % showing susceptibility to Cefotaxime, 35.1 % to Piperacillin-tazobactam combination, and a mere 12.3 % remaining susceptible to Ciprofloxacin which was 19 % in 2021. Similarly, Klebsiella's susceptibility rates are alarmingly low, with only 21.3 % showing susceptibility to Cefotaxime, 22 % to Piperacillin-tazobactam combination, and 42.2 % to Imipenem which is a notable drop from the 64.8 % susceptibility observed in 2016 from all type of samples except faeces and urine [14].

Interestingly, findings from NCDC closely align with those concerning patterns exhibiting significant resistance rates in *E.coli*, with over 80 % resistance to Ampicillin and more than 70 % resistance to the third-generation Cephalosporin antibiotic, Cefotaxime. Klebsiella, another prominent pathogen, has shown varying resistance rates, including 34–52 % resistance to Amikacin, 69–83 % resistance to Cefotaxime, and 60–68 % resistance to Ciprofloxacin across all tested specimens, as reported by NCDC [15].

These findings collectively emphasize the pressing issue of antibiotic resistance within these bacterial populations. The data underscores the urgent need for comprehensive strategies to address this growing concern, focusing on prudent antibiotic use, infection control measures, and the development of new therapeutic options to combat these resistant pathogens effectively.

2.1.2. AMC surveillance

India issued its National Action Plan on AMR (NAP-AMR) for the period–2012-2017 [26]. Although the ICMR launched the Antimicrobial Stewardship, Prevention of Infection, and Control (ASPIC) initiative in 2012 under NAP-AMR to address the issue of antimicrobial consumption (AMC), comprehensive AMC surveillance among humans has not been established. Studies indicate a significant increase in antimicrobial

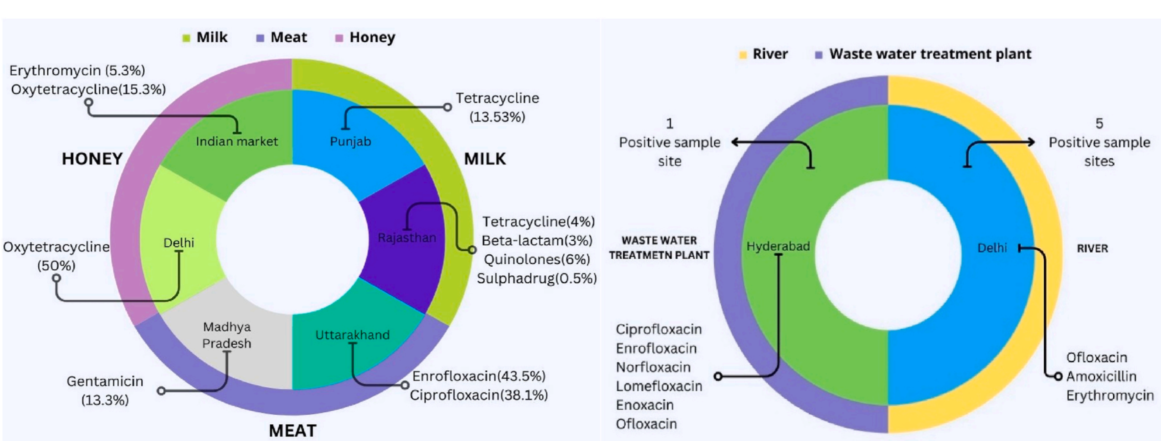

Fig. 1. Studies showing the presence of antibiotic residues in certain areas in India. Ref. [77–84].

consumption in India, rising from 3.2 to 6.5 billion DDD among LMIC between 2000 and 2015 [12], recent data clocked around 8 billion DDD consumption of antimicrobial consumption in 2020 [9]. Since 2010 till 2020, there has been around 47.40 % change in the antibiotic total use in India. Despite these figures, there are still no national-level measures for monitoring antibiotic usage.

Recently, the Central Drugs Standard Control Organization (CDSCO) made efforts to improve AMC surveillance. CDSCO directed the Pharmacovigilance Programme of India (PvPI) to establish a surveillance program across various hospitals through 203 monitoring centers. This program focused on monitoring antibiotic usage, documenting adverse reactions, and reporting cases of antibiotic resistance. Additionally, the monitoring centers under PvPI conduct monthly awareness programs on antibiotic misuse involving healthcare professionals and community members [27].

2.1.3. Regulation

Certain regulations have been implemented by several organizations to combat the use of antibiotics in humans. To address the issue of the over-the-counter (OTC) sale of antibiotics in India, the government introduced Schedule H1 under the Drugs and Cosmetics Rules [28]. This regulation mandates that antibiotics can only be dispensed with a valid prescription, with the aim of optimizing their use and preventing misuse or overuse. The National Regulatory Body (CDSCO) has advised various professional bodies belonging to the Medical, Pharmacy, Dental, and Nursing departments to raise awareness among registered candidates regarding the importance of adhering to standard treatment guidelines when prescribing antibiotics [29]. The ICMR also issued hospital infection control guidelines for judicious antibiotic use within healthcare facilities [7]. However, despite such efforts, the practice of selling OTC antibiotics and non-judicious antibiotic use continues to be prevalent in the country [30].

India took several other initiatives under NAP-AMR to develop a State Action Plan for Containment of Antimicrobial Resistance (SAPCAR). However, only a few states, such as Kerala, Madhya Pradesh, and Delhi, have successfully established their state action plans [26], revealing a significant implementation gap.

2.2. Animal husbandry sector

2.2.1. AMR surveillance

The increasing rate of AMR among animals, which are vital assets to humans, necessitates the development and implementation of an AMR surveillance system. Such a system would provide valuable insights into the current status of AMR spread, and assist policymakers in making informed decisions to address and mitigate AMR in animals effectively. Therefore, the Indian Council of Agricultural Research (ICAR) initiated the Indian Network of Fisheries and Animal Antimicrobial Resistance (INFAAR) surveillance system in 2018 to monitor AMR in India's livestock and fisheries sectors. It currently operates through 18 organizations in 20 centers across the country but has yet to be fully developed [31]. The highest resistance among *E.coli* is observed with Ampicillin at 69.6 % and Tetracycline at 38.6 %. In *Salmonella* spp., both Ampicillin and Tetracycline exhibit approximately 16.5 % resistance as per the data of 2020 [9].

2.2.2. AMC surveillance

In India, there is a lack of a national surveillance system to monitor AMC in the veterinary sector despite the unregulated and widespread use of antibiotics for growth promotion in animal rearing and fisheries [32,33]. Furthermore, it is anticipated that by 2030, the estimated total antimicrobial usage will reach around 2236.74 tonnes, in contrast to the 2160.02 tonnes estimated for the year 2020 [9]. It is worth noting that the country accounted for approximately 3 % of the world's consumption of antimicrobials in food animals in 2010, a figure expected to rise to 4 % by 2030 [34]. This trend has resulted in the increased presence of antibiotic residues in animal-based food products in the upcoming years. India is also a major exporter of shrimp and freshwater prawns, where antibiotic use is common to prevent infections in aquaculture. Between 2012 and 2015, the Rapid Alert System for Food and Feed (RASFF), a tool designed by the European Commission, rejected 17 shrimp consignments due to antibiotic residues exceeding permissible tolerance limits. In comparison, the United States Food and Drug Administration (USFDA) refused 27 shrimp consignments in 2020–2021 for the same reason [35,36]. Such instances that highlight the unchecked and inappropriate use of antibiotics in animals pose a risk for AMR propagation within the community.

2.2.3. Regulation

In 2018, a veterinary unit was established under the CDSCO to examine the use, import, registration, and licensing of veterinary vaccines and drugs including antibiotics [37]. CDSCO had previously issued an advisory on the rational use of antibiotics, including steps to ensure that animal-sourced food products adhere to safe antibiotic residue limits. The Drug and Cosmetic Rule 1945 was amended to make it essential to specify withdrawal periods on labels of veterinary medicines used in food-rendering animals because the lack of adherence to prescribed drug withdrawal periods results in products having antibiotic residues [29,38]. The Department of Animal Husbandry and Dairying (DAHD) advised all state/union territories to prohibit the use of antibiotics as growth promoters in feed supplements and to restrict access to antibiotics to registered users [39].

The Bureau of Indian Standards (BIS) 2007 recommended eliminating antibiotics with systemic action, such as doxycycline, tetracycline, nitrofuran, chloramphenicol, and furazolidine, as growth promoters in poultry feed [40]. Alternatively, the Food Safety and Standards Authority of India (FSSAI) has endorsed the BIS standard, requiring manufacturers of feed for food-producing animals to comply with the Indian Standard (IS2052:2009), which specifies sampling and testing procedures for compounded cattle feed [41]. The Coastal Aquaculture Authority (CAA) Act 2005 issued guidelines for using chemicals and drugs in aquaculture, prohibiting the use of 20 antibiotics and allowing the use of four within specified MRL [42]. In the agriculture sector, the Central Insecticide Board and Registration Committee (CIBRC) issued a draft order in August 2021 to completely ban the agricultural use of 2 antibiotics streptomycin and tetracycline [43].

The presence of regulations is crucial for managing antibiotic residues in animal-based food products; however, achieving full effectiveness remains a challenge. Regulators face several obstacles in enforcing these regulations, with one significant hurdle being the lack of awareness among farmers regarding proper antibiotic use. Studies conducted in India reveal instances where farmers are unaware of the withdrawal period for antibiotics, leading to the inadvertent incorporation of antibiotic residues in animal-derived food [44]. Another critical constraint arises from the easy accessibility of veterinary medicines to farmers, coupled with the unavailability of registered practitioners in their localities. Consequently, farmers often turn to para-veterinarians for advice and administer antibiotics to their animals without the involvement of qualified veterinarians [45,46]. This scenario highlights the importance of addressing knowledge gaps and improving access to veterinary expertise to ensure effective regulation and minimize antibiotic residues in the food supply chain.

2.3. Food sector

2.3.1. AMR surveillance

A surveillance system to monitor antibiotic residues and Antibiotic-Resistant Bacteria (ARBs) in the food sector is yet to be established. However, the FSSAI has implemented several standards and regulations to monitor food contaminants across the country, even detecting antibiotics in milk samples [47]. The FSSAI operates a network of 227 primary, 20 referral, 12 National Reference, and two Ancillary National

Reference Laboratories (ANRL) that conduct tests to assess the quality of food [48].

2.3.2. AMC surveillance

This sector lacks an integrated surveillance system that tracks the consumption of antibiotics incorporated in food consumed by humans. Nonetheless, studies have shown the presence of antibiotics in foods for human consumption. For example, a study conducted on Indian market food specimens identified bacterial isolates, with *Klebsiella pneumoniae* being the most prevalent (52.6 %), followed by *Citrobacter koseri* (18.4 %). Predominantly, these isolates showed resistance to aminoglycosides and third-generation cephalosporins [49]. Such studies highlight the need for stringent regulations to address antibiotic use in the food sector nationwide.

2.3.3. Regulation

The FSSAI, established in 2008, is the national regulator responsible for ensuring food safety in the nation. It analyzes contaminants in food and establishes bans and tolerance limits on specific antibiotics used in shrimp, fish, honey, and animal-origin food products [50]. It has constantly formulated new regulations, issuing 11 final notifications and 17 draft notifications, including amendments to existing standards for various food products. Various schemes like, Mobile Food Testing Laboratories (MFTL), and Food Safety on Wheels (FSW), are being provided in States/UTs across the country to boost the testing of the food articles. The scheme introduces a total of 173 (FSWs) provided under the Central Sector Scheme to address testing infrastructure gaps in remote areas. Towards scaling up food testing, awareness, and capacity building as per the vision document, a new version of FSW called modified FSW has been designed. During the year 2021–22, FSSAI analyzed 1,44,345 samples for contaminants and antibiotic residues and launched 28,906 civil cases nationwide. Initiatives like “Eat Right India” were also launched by FSSAI to promote safe and healthy diets to the people [48].

In 2001, the Ministry of Commerce and Industry (MoCI) established Maximum Residual Limits (MRLs) for antibiotics in marine/seafood exported from India to prevent the occurrence of antibiotic residues in food [51]. Other bodies under MoCI, such as the Marine Products Export Development Authority (MPEDA) and the Agriculture and Processed Food Products Export Development Authority (APEDA), focus on developing export quality and food standards. The MPEDA initiated the National Residue Control Plan (NRCP) to monitor antibiotic residues in marine foods, issuing 12841 pre-harvest Test certificates based on screening of the shrimp samples for antibiotic residues during the year 2021–22. They have periodically expanded laboratory capacities for increased food sample testing to enhance the spectrum of testing food samples [52]. Meanwhile, APEDA inspects all food products except marine products [53]. The Export Inspection Council (EIC) is another MoCI body that is responsible for certifying the quality of food exported. EIC has implemented residue monitoring plans meeting European Commission requirements for various animal-origin foods, testing around 9708 food samples against the Residues Monitoring Plan (RMP) and National Residues Control Plan (NRCP) during 2021–22 [54].

2.4. Environment

2.4.1. AMR and AMC surveillance

There is no surveillance system for monitoring antibiotic residues in critical areas of the environment, such as rivers, lakes, and soil, which allows the accumulation of pollutants, including heavy metals, detergents, disinfectants, and antibiotic residues from industrial pollution. Further, such accumulation of pollutants into the environmental bodies poses a risk of spreading ARBs and ARGs [55]. The presence of antibiotics and ARBs detected in river, surface water, and wastewater samples across different regions of India further highlights the unregulated use of antibiotics (Fig. 1).

2.4.2. Regulation

Although there is no particular surveillance system for this sector, the government has taken steps to address antibiotic misuse. In line with this issue, the Ministry of Environment, Forest, and Climate Change (MoEFCC) drafted a notification on January 23, 2020, which established antibiotic residue values for the effluent of 121 antibiotics [56]. In addition, the Central Pollution Control Board (CPCB) under MoEFCC has developed emission standards for pharmaceutical plants but does not include antibiotic monitoring [57].

3. Discussion

We have highlighted the range of stakeholders working in the regulation, surveillance, monitoring, and implementation in each of the One Health sectors in India at the national level (Table 1). The lack of establishment and implementation of surveillance systems across the animal husbandry, Food Safety, and Environmental sectors is pushing the emergence of AMR to another level. The resources and governance structures necessary for implementing the One Health concept, especially in resource-stretched settings like India seem to be nascent.

The consequences of low Antimicrobial Resistance (AMR) tracking patterns carry multifaceted risks across different levels. At the local level, a decline in tracking could significantly deteriorate patient health. The absence of a reliable guide for clinical decision-making, especially concerning animals where surveillance is less robust, could lead to suboptimal treatment outcomes. Given that clinical decisions often precede the identification of the causative organism and Antibiotic Susceptibility Testing (ABST) results, surveillance data becomes essential in guiding practitioners to make informed choices regarding antibiotic prescriptions.

On a national scale, the lack of data hinders the formulation of effective health policies and responses to health emergencies. The absence of comprehensive surveillance data obscures the true health impact of AMR and impedes the evaluation of control measures both within healthcare facilities and the broader community. Without robust tracking, it becomes challenging to identify, assess, and address the effectiveness of measures aimed at curbing AMR. Expanding to the global context, the deficiency in tracking patterns denies the ability to provide early warnings about emerging threats and identify long-term trends related to AMR. Effective surveillance is paramount in profiling geographical patterns and trends in AMR-related infections within specific settings. Without a well-developed surveillance system, the global community would lack the capacity to anticipate, respond, and strategize against the evolving landscape of AMR, thereby compromising our collective ability to address this global health challenge proactively.

One of the key stakeholders in the One Health framework is the animal husbandry sector, which requires additional resources including infrastructure, human resources, and program support. Despite supporting a large population of animals, the veterinary sector in India faces a significant workforce gap. Although India has surpassed the WHO-recommended doctor-population ratio of 1:1000 for Public Health [58], the number of veterinary practitioners is only 67,784 (as of 2015) for a livestock population of 512 million [59,60] leading to a deficiency of adequate services being provided to livestock.

Furthermore, there is a severe shortage of well-functioning laboratories that are essential for the diagnosis and prescription of antibiotics for animals. India, with its substantial cattle population of 192.49 million (bovine: 302.79 million) in 2019, only has 282 laboratories across the country, including state, central, and regional laboratories [17,61]. Consequently, the necessary diagnostic tests, such as antibiotic susceptibility testing (ABST) to determine appropriate antibiotics, are often neglected and conducted only when therapy fails [45]. A qualitative interview study conducted in Orissa, India revealed that the lack of good laboratories and staff responsible for the improper use of antibiotics [62]. In another study, it was discovered that Veterinarians face challenges in collecting samples from animals. The absence of facilities

Table 1
A summary of the Surveillance systems, ministries involved, policies, and recommendations for each particular sector in One Health.

Topic	Human Health	Animal husbandry	Food safety	Environment
Surveillance systems	• AMRSN (by ICMR) • NARS-Net (by NCDC)	• INFAAR (by ICAR)	–	–
Capacity	AMRSN (20 regional laboratories, 7 Nodal centers across the nation). NARS-Net (40 laboratories in 31 States/Union Territories)	INFAAR (11-Veterinary and animal science institute, and 8- Fishery institute)	–	–
Ministries	MoHFW (Ministry of Health and Family Welfare)	MoFAHD (Ministry of Fisheries, Animal Husbandry and Dairying) MoAFW (Ministry of Agriculture and Farmers Welfare)	MoCI (Ministry of Commerce and Industry)	MoEFCC (Ministry of Environment, Forest and Climate Change)
Organizations	ICMR (Indian Council of Medical Research) NCDC (National Centre for Disease Control CDSCO (Central Drugs Standard Control Organisation).	ICAR (Indian Council of Agricultural Research), DAHD (Department of Animal Husbandry and Dairying), CAA (Coastal Aquaculture Authority), CDSCO (Central Drugs Standard Control Organisation).	FSSAI (Food Safety Standards of India) MPEDA (Marine Products Export Development Authority), APEDA (Agricultural and Processed Food Products Export Development Authority) EIC (Export Inspection Council), CIBRC (Central Insecticides Board and Registration Committee).	CPCB (Central Pollution Control Board)
Policies	Introduction of Schedule H1 under Drug and Cosmetics rules to regulate Over-the-counter sale of antibiotics. Guidelines issuance for hospital infection control stating judicious use of antibiotics by healthcare workers. Advice to professional bodies belonging to the Medical, Pharmacy, Dental, and Nursing departments to adhere to standard treatment guidelines to combat AMR.	Compulsory labeling of withdrawal periods on antibiotics intended for animal use. Setting up of Maximum Residual Limits (MRLs) for antibiotics in feed. Advisory to States/Union Territories to prohibit the use of antibiotics as growth promoters in animal feed. Formation of a veterinary unit that examines the use/import/licensing of veterinary drugs including antibiotics.	Imposing a ban on the use of certain antibiotics in food. Setting up tolerance limits for antibiotic residues in food and food products. Quality certification after inspection of residues in the food to be exported	Establishment of the antibiotic residue of 121 antibiotics for the effluents from the industry.
Recommendation	Creating awareness among people about the appropriate use of antibiotics in particular infections.	Implementation and enhancement of the surveillance system that monitors antibiotic use in animals and resistance rates in pathogens found in animals. Setting up of laboratories with sufficient capacity for rapid and reliable diagnostic tests. Rise in awareness regarding the judicious use of antibiotics in animals.	Establishment of a surveillance system to monitor antibiotic use and detect antibiotic-resistant pathogens in various food and food products.	Establishment of a surveillance system to monitor the disposal of antibiotics into the environment by industries, hospitals, and other sources.

for proper collection, preservation, and transportation to nearby laboratories hindered the effective diagnosis of diseases [63]. The limitation in laboratory infrastructure, coupled with poor accessibility to healthcare and inadequate adherence to diagnostic practices, contributes significantly to the inappropriate use of antibiotics and consequently, the rise of antimicrobial resistance (AMR).

Another significant concern is the high accessibility of antibiotics and the prevalent practice of self-medication in both humans and livestock, reaching approximately 73 % in certain areas of India [64–66]. Despite being prescription-only drugs, over-the-counter (OTC) sales and the use of antibiotics without proper medical supervision remain common in the country [30]. Several studies have reported the use of OTC antibiotics by individuals [67] and animals [68]. This self-medication practice poses a substantial risk of antibiotic resistance development.

In addition, there is a lack of comprehensive data, including sentinel surveillance, on antimicrobial use in agriculture, animal husbandry, livestock production, and food products [39]. Although antibiotic use in animal feeds has been reported to be high in India [68], such data are generally under-reported. This scarcity of data hampers the ability to differentiate between therapeutic and growth-promoting antimicrobial use, making the development of targeted interventions challenging.

Moreover, the pricing of drugs, including antibiotics, is regulated by the National Pharmaceutical Pricing Authority of India (NPPAI) under the Drugs Prices Control Order (DPCO) 2013. However, there is no differentiation between veterinary and human antibiotic use [69]. Anecdotal evidence suggests that antibiotics intended for human use are being purchased and administered to farm animals as quick solutions, which require attention.

Among the challenges in enforcing the regulations the major challenge is the prescribing of antibiotics by the Informal Providers (IPs) in India. The IPs have existed in the country for over a decade. This challenge is deeply rooted, as highlighted in a survey conducted by Das et al. across 19 states in India. The findings indicated that among the total healthcare providers surveyed, a mere 8 % held an MBBS, while a substantial 68 % were Informal Providers [70].

An additional hurdle in this landscape is the dearth of short courses aimed at educating IPs about the judicious use of antibiotics. The absence of such training contributes to the improper and excessive prescription of antibiotics by these providers. Furthermore, the shortage of inspection authorities tasked with monitoring antibiotic prescriptions exacerbates problem. A study conducted in West Bengal revealed a contrast between the 150 inspectors overseeing 50,000 registered pharmacies in the state [71]. This scarcity of oversight allows for ill practices in antibiotic prescriptions to persist in the country.

Another obstacle in regulation enforcement is that online pharmacies or e-pharmacies which supply drugs quickly and easily are also the areas where the regulatory bodies have no grip over sales control. Although the government has made certain regulations to regulate the online sale of medicines, the easy access of medicines to common people is creating an issue in the enforcement of the regulations. The challenges extend where pharmacies may prioritize profit maximization over adhering to regulations. Competitive pressures among pharmacies can drive the unauthorized sale of drugs without prescriptions. The nexus of corruption and the political consequences further impede the effective inspection of pharmacies, requiring a careful prioritization of resources and enforcement activities [30].

A noteworthy aspect is the inaccessibility of doctors to farmers in certain districts of India, compelling individuals to procure antibiotics from nearby pharmacies due to either the unavailability or high consultation fee of the doctor. A study underscored the low awareness among farmers regarding antimicrobial resistance (AMR), attributing this knowledge gap to insufficient outreach by healthcare professionals [72].

Adding to the complexities, the high demand for food amidst a growing population exerts pressure on farmers to increase production [45]. This, in turn, drives the use of antibiotics as growth promoters, contributing to the broader challenge for regulatory bodies to enforce the laws and regulations.

Furthermore, as one of the largest producers of pharmaceuticals, India generates a significant amount of waste that is often improperly disposed of, leading to water body contamination [73]. Inadequate monitoring of industrial effluents and improper waste treatment systems contribute to the rise in antimicrobial resistance rates, as hospital waste contaminates water bodies with antibiotics and infectious pathogens [74,75].

To effectively tackle the challenge of Antimicrobial Resistance (AMR), a series of strategic interventions are proposed, aiming to not only raise public awareness but also engage stakeholders in a collaborative effort to mitigate AMR. One notable approach involves launching media campaigns inspired by successful models in developed countries, strategically designed to capture the attention of the masses. These campaigns, featuring government officials, seek to educate and mobilize a broad audience. In parallel, a promising initiative is the introduction of special incentives to practitioners and pharmacists. Drawing inspiration from the policy of NHS England, offering rewards to clinical servicemen for a substantial reduction in antibiotic sales [76], such incentives serve as powerful motivators. Also, the pharmacists could receive special accreditation from the government upon successfully reducing antibiotics sales, providing them with means to enhance their business profitability.

The importance of stakeholder engagement is emphasized through regular audits and feedback sessions with practitioners. This proactive approach not only encourages the practitioners but also ensures they stay well-informed about the evolving landscape of AMR. Technological innovation is also leveraged to influence public awareness. The incorporation of smart applications not only promotes the judicious use of antibiotics but also empowers patients to self-diagnose and acquire medications only when necessary. Furthermore, collaboration with non-governmental organizations (NGOs) and other social worker groups becomes crucial, particularly in monitoring antibiotic waste disposal. Their involvement in environmental surveillance helps establish a robust system to detect and restrict the improper disposal of antibiotics, safeguarding both public health and the environment.

Looking beyond national boundaries, a strategic alliance with developed nations becomes imperative. This collaboration aims to foster the development of rapid and accessible diagnostic services for both practitioners and patients. Additionally, a comprehensive surveillance system spanning all one health sector is envisioned, a pivotal step in managing the challenges posed by the growing population in India. Together, these interventions form a holistic and forward-looking strategy to combat AMR and promote sustainable healthcare practices. Addressing the growing burden of antimicrobial resistance requires synchronized actions and long-term commitment from stakeholders. National-level policymakers in animal health/husbandry, climate change, human health, agriculture, and food safety must take the lead in securing political commitment, ownership, and a joint action plan across the One Health Framework.

4. Conclusion

In conclusion, this mini-review delves into the crucial issue of antimicrobial resistance (AMR) regulation in India, specifically focusing on its status across four significant sectors: Human health, Animal husbandry, Environment, and the food sector. Through a comprehensive analysis, it becomes evident that while the human health sector boasts a robust surveillance system, the remaining sectors are alarmingly deficient in this regard. This disparity in surveillance underscores a critical gap that needs immediate attention. Furthermore, insufficient effective policies to mitigate AMR across these sectors highlight a pressing need for comprehensive and well-structured regulatory frameworks. Addressing these challenges is imperative to safeguard public health and environmental well-being, reinforcing the urgency of bolstering AMR regulation across all sectors in India.

CRediT authorship contribution statement

Vijay Pal Singh: Writing – review & editing, Methodology, Investigation, Conceptualization. **Diksha Jha:** Writing – review & editing, Project administration. **Bilal Ur Rehman:** Writing – original draft, Methodology, Formal analysis, Data curation. **Virendra S. Dhayal:** Methodology, Formal analysis, Data curation, Conceptualization. **Mahesh Shanker Dhar:** Writing – review & editing, Supervision, Formal analysis. **Nitin Sharma:** Writing – review & editing, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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