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The risk of antimicrobial resistance and zoonotic diseases in India's dairy value chain, and how we can mitigate the public health threat through interventions

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Abstract

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India is the world's largest producer of milk and milk products with small-scale farms dominating the dairy industry. The infrastructure is inadequate, and quality control is minimal. India has a high burden of infectious and zoonotic diseases due to a lack of awareness, poor hygiene practices, poverty, and limited access to medical services. There is however unrestricted access to medicines. Antibiotics are widely used in dairy animals for therapeutic and prophylactic purposes and are sometimes given in large quantities to prevent diseases.

This thesis assessed knowledge, attitude, and practices (KAP) regarding antibiotics, antimicrobial resistance (AMR), milk safety, and zoonotic diseases. Surveys among dairy farmers and milk vendors were conducted to assess their knowledge and practices regarding milk safety, antibiotics, and milk handling. Milk samples from dairy farms were analyzed for antibiotic residues and milk samples from vendors were analyzed for antibiotic-resistant bacteria. Veterinary practitioners were interviewed to understand their knowledge and perceptions. Interventions were carried out to raise awareness and a follow-up survey was conducted to assess knowledge change.

The knowledge of dairy farmers related to antibiotics, AMR, and zoonotic diseases was quite low. There were 5.9% positive samples with antibiotic residue levels over the maximum residue limit. Farmers admitted using antibiotics without a veterinarian's approval and reported a lack of veterinarians. Milk vendors were unaware of antibiotics and AMR. They knew very little about milk hygiene and sold raw milk. Most (64.5%) vendor milk samples had antibiotic-resistant bacteria. Due to a lack of diagnostic facilities, veterinarians gave antibiotics based on their knowledge of diseases and symptoms without testing. A follow-up study found that farmers who attended intervention training showed an improvement in their knowledge level. This thesis offers a glimpse of the many factors that are contributing to the inappropriate use of antibiotics in the livestock industry of India. The level of knowledge can be improved with regular discussions. In addition to improving veterinary facilities, stakeholders in the informal dairy value chain should get frequent training.

Keywords: antibiotics; AMR; dairy farmer; milk vendor; informal dairy value chain; veterinarian; zoonotic diseases; milk hygiene; milk handling

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***"The woods are lovely, dark, and deep.
But I have promises to keep and miles to go before I sleep"- Robert Frost***

This thesis is dedicated to my parents, my husband, and my mentors for their unwavering support and encouragement.

List of Papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.

I. **Sharma G**, Kumar N, Leahy E, Shome BR, Bandyopadhyay S, Deka RP, Shome R, Dey TK, Lindahl FJ. Understanding Antibiotic Usage on Small-Scale Dairy Farms in the Indian States of Assam and Haryana Using a Mixed-Methods Approach—Outcomes and Challenges. (2021) *Antibiotics*, 10, 1124.

II. **Sharma G**, Mutua F, Deka RP, Shome R, Bandyopadhyay S, Shome BR, Kumar N, Grace D, Dey TK, Venugopal N, Sahay S & Lindahl FJ. A qualitative study on antibiotic use and animal health management in smallholder dairy farms of four regions of India. (2020) *Infection Ecology & Epidemiology*, 10:1, 1792033

III. **Sharma G**, Mutua F, Deka RP, Shome R, Bandyopadhyay S, Shome BR, Kumar N, Grace D, Dey TK and Lindahl J. Comparing the Effectiveness of Different Approaches to Raise Awareness About Antimicrobial Resistance in Farmers and Veterinarians of India. (2022) *Front. Public Health*, 10:837594.

IV. **Sharma G**, Leahy E, Deka RP, Shome BR, Bandyopadhyay S, Dey TK, Kumar N, Lundkvist Å, Grace D, Lindahl FJ. Antibiotic use, knowledge, and practices of milk vendors in India's informal dairy value chain. *Manuscript submitted in Frontiers In Sustainable Food Systems.*

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Contents

Abbreviations

AMR	Antimicrobial resistance
ANOVA	Analysis of variance
CBHI	Central Bureau of Health Intelligence
CDB	Community development block
CI	Confidence interval
DPA	Dipicolinic acid
ESBL	Extended spectrum beta-lactamase
FGD	Focus group discussion
FMD	Foot and mouth disease
FSSAI	Food Safety and Standards authority of India
ICAR	Indian Council of Agricultural Research
ICMR	Indian Council of Medical Research
IDSP	Integrated Disease Surveillance Project
IEC	Information, education, and communication
IPC	Infection, prevention and control
JE	Japanese encephalitis
KAP	Knowledge, attitude, and practices
KFD	Kyasanur forest disease
KII	Key informant interview
KMF	Karnataka Milk Federation
MDR	Multi drug resistant
MRL	Maximum residue limit
MRSA	Methicillin resistant *Staphylococcus aureus*
NCDC	National Centre for Disease Control
NDDB	National Dairy Development Board
NDRI	National Dairy Research Institute
NHP	National Health Policy
NIVEDI	National Institute of Veterinary Epidemiology and Disease Informatics

NLP	National Livestock Policy
NPTRD	National Policy for Treatment of Rare Diseases
NRCP	National Rabies Control Programme
NWAP	National Wildlife Action Plan
OTC	Over the counter

Introduction

India's immense livestock population includes 193.5 million cattle and 109.9 million buffaloes (1). With an annual output of 146 million tons, India is the world leader in the production of milk and dairy products, accounting for 18.5% of global output (2), and dairy is currently India's most valuable commodity. However, productivity in many units is very low. Millions of small and marginal farmers with 2-5 animals produce 5 liters of milk on average. Rural small-scale milk producers contribute to 62% of the country's total milk production (3). The milk produced on these small-scale dairy farms not only contributes to meeting the nutritional needs of the household, but it also serves as a source of income for these farmers. The majority of these farms have inadequate infrastructure and quality control. They have low input costs, occupy less than one hectare of land, and rely on family labor (2,4). The farmers frequently engage in behaviors that have the potential to harm the public health, such as improperly cleaning of the farm or barn, failing to wash their hands or udders before milking, and using antibiotics to promote production (2,4,5).

In India, the intensification of livestock business over the years along with urbanization, deforestation, population growth, increased mobility, has resulted in the coexistence of animals and humans living in a closer proximity. Zoonotic illnesses are present around the world, but they are particularly problematic in India, where 68% of the labor force is employed in agriculture, which necessitates regular close contact with domestic animals and poultry as well as exposure to animals that are ill or infected (6). In recent years, zoonoses such as brucellosis, rabies, Japanese encephalitis (JE), leptospirosis, etc. have reemerged in India. Outbreaks of both zoonotic and animal diseases occur frequently on the dairy farms, causing high morbidity (7).

In India, antibiotics are frequently administered to livestock for both therapeutic and prophylactic purposes. Sometimes, bulk doses are given for prophylactic purposes, and antibiotics fed to livestock in extremely small amounts may be used for growth promotion (7–9). Animals receive antibiotics for a variety of reasons, including routine dosing and, in some cases, unintentional administration by farmers who feed their livestock commercially available feeds containing antibiotics. Antibiotics are also routinely administered to animals before and after surgical procedures, during and after transportation, and in other situations when animals are under stress (8). In the smallholder dairy farms of India, farmers are often the ones who determine when to use antibiotics and treat the animals without consulting veterinarians since extension systems are underdeveloped (2,4), and antibiotics are available over the counter (OTC), without prescriptions. India is anticipated to be the fourth highest consumer of antibiotics in food animal production by 2030, but there are still no precise estimates of antibiotic usage in animals (7). Eleven of the fifteen antimicrobials the WHO claims are crucial for human health, and the EU doesn't allow in animal feed, are utilized in Indian poultry feed (7). Farmers, quacks, and inexperienced para-vets use antibiotics indiscriminately (2,7). Studies across the country have identified resistant bacteria and antimicrobial residues in different animal products (10). Antibiotic residues of various antibiotics used in treating mastitis and infectious disorders in dairy cattle have been found in milk samples from different Indian states (5,11–13).

Antimicrobial resistance (AMR) has increased alarmingly in the nation as a result of the inappropriate use of antibiotics in both the human and animal health sectors (14). India has few laws and regulations governing antibiotic use in food animals, which makes rational antibiotic use in this sector difficult (7). There is also a lack of strong monitoring and surveillance mechanisms to check if these regulations are implemented at a ground level or not (5,7).

AMR emergence and spread are complex issues aggravated by the expectations and interactions of prescribers and patients, as well as limited awareness, a permissive regulatory framework, and easy access to antimicrobials in developing countries (5,15). Irrespective of size of dairy farms, antibiotics are used in the farms and the knowledge related to antibiotics, antimicrobial resistance, zoonotic diseases, and hygiene is almost negligible in India (2). With regard to antibiotic prescription patterns, very little research has been done to understand prescriber and consumer behavior in Indian settings. There are currently minimal training programmes or materials accessible to instruct professionals and employees in the veterinary and health care industries about antibiotics, AMR, zoonotic diseases (16). Additionally, not many measures have been made to lower the public health risk of developing zoonotic illnesses among those most exposed, such as farmers or veterinarians.

This research work was conducted to understand the knowledge and practices of various stakeholders involved in the dairy value chains of India regarding common zoonotic diseases, antibiotics, milk handling, and AMR. The gravity of the situation was analyzed by using mixed methods to understand knowledge and practices of antibiotic use. In addition, laboratory analyses were also conducted of milk samples taken from these dairy farms to test for antibiotic residues, and from vendors to test for the presence of antibiotic resistant bacteria. Furthermore, extension activities and training were performed to estimate the impact of interventions on the knowledge levels and reduce the public health risk of AMR and zoonotic diseases.

Dairy sector of India: an overview and challenges

Over the past five decades, India has gone from being a country with a severe milk shortage to the world's largest milk producer. In 2006, India produced more than 100 million tons of milk. This amazing success can be traced back to a government programme called Operation Flood or "White Revolution", which ran from 1970 to 1996 and put a strong focus on dairy development activities (17). In this project, a network of village cooperatives was set up to buy and sell milk and connect milk sheds in rural areas to markets in cities. Milk production and productivity were improved by making sure that veterinary services, artificial insemination (AI), feed, and farmer education were readily available in the project areas. The investment paid off, leading to a 4–5% increase in production every year (18). With a production value of 1.8 billion rupees (USD 39 million) in 2004, dairy is currently India's top-ranking commodity. India has the most dairy animals in the world, including approximately 300 million bovines (19). Agriculture and livestock keeping engages approximately 70% of India's population (20). Small and marginal farmers own 33% of the land and approximately 60% of all female cattle and buffaloes. On average, 75% of rural households own two to four animals (21). Dairy is often a component of the farming system, not a separate business. Feed is mostly crop residue, whereas cow dung is important for manure. Dairying generates consistent income, whereas agriculture generates seasonal income. Dairy farming accounts for roughly one-third of rural income (18). Farms themselves consume approximately 50% of the milk produced (22). India's demand for dairy products is anticipated to increase substantially over the next few years due to an increase in milk consumers, rising incomes, and a growing interest in nutrition. The National Dairy Development Board (NDDB) estimates that the demand for milk is likely to reach 180 million tons by 2022 (3). Dairy products that have been pasteurized and packaged are becoming more popular in cities. Because of its flavor and perceived freshness, unpackaged, raw milk from a local milkman/vendor is however still preferred in many parts of the nation (18,21). Because a large proportion of milk and milk products are sold through the informal channel, the organized sector's share of milk procurement is very low. The informal value chain encompasses approximately 41% of the country's milk and milk products, accounting for about 75% of the marketable surplus of milk (18). The informal sector consists of a large part of the village milk vendors who procure raw milk from farmers and sell it in urban and peri-urban areas directly to consumers, small private processors, and hotels (18).

Indian dairy infrastructure is dominated by the small-scale dairy farms, but these small-scale dairy households face numerous challenges, including low milk prices; a lack of quality feed and fodder; low genetic potential of dairy animals, resulting in low productivity levels; inadequate animal health-care facilities; inadequate extension services, and inadequate rural infrastructure.

Furthermore, the constraints include seasonal availability and feed costs; weak milk marketing and low milk prices; land availability; waste disposal and pollution issues; infectious diseases, and a shortage of capital (3). The farmers face massive losses due to diseases like mastitis and seasonal outbreaks of diseases like Foot and mouth disease (FMD) that decrease the milk production substantially (3,23). Mastitis, especially sub-clinical mastitis, remains a huge problem in many dairy herds with about 70% of all losses being perceived to be due to the infection (22–24).

Zoonoses in India: outline, policies, and challenges

In India, the huge animal and human population increases the probability of human-animal contact and spread of zoonoses (6,25). There are numerous risk factors that contribute to the occurrence of emerging zoonotic diseases in the country such as the explosive population increase, urbanization, deforestation, climate change, natural migration of animals, travel and tourism (6). Other risk factors include confined spaces, poor personal hygiene and lack of awareness (26). In India, major zoonotic diseases that affect public health are rabies, brucellosis, toxoplasmosis, cysticercosis, echinococcosis, Japanese encephalitis (JE), plague, leptospirosis, scrub typhus, Nipah disease, trypanosomiasis, Kyasanur forest disease (KFD), and Crimean-Congo hemorrhagic fever (CCHFV). In 2019, 110 cases of rabies, 1674 cases of JE, and 4380 cases of Kala-azar (leishmaniasis) were provisionally reported by the Central Bureau of Health Intelligence (CBHI) (27). Many human rabies cases in India go undetected, are misdiagnosed, or unreported. Around 35% of the estimated global 59,000 annual human deaths due to dog-mediated rabies occur in India (28). Plague still keeps resurfacing in different parts of India (25). Many districts in Bihar and Uttar Pradesh are affected by JE epidemics every year (29). Brucellosis is highly prevalent in India and causes an estimated annual economic loss of INR 24 crores (30,01,745 USD) (25). Brucellosis not only affects livestock populations in India, but it is also a significant occupational hazard for humans involved in livestock-related activities (30).

Although the burden of zoonotic diseases in India is quite high there are limited national programs and policies that focus on controlling the spread of these zoonotic diseases. With the exception of a brief mention in the National Livestock Policy (NLP) 2013, National Wildlife Action Plan (NWAP) 2017-2031, and the National Policy for Treatment of Rare Diseases (NPTRD) 2018, zoonotic diseases tend to have very little visibility or expression in the current policy agenda setting (31). NLP 2013 stated that preventing, controlling, and eradicating different disease problems (including zoonoses) is essential to protecting livestock health, but it did not outline any specific processes or strategies for doing so (32). Intriguingly, despite its ambitious and well-intended focus on providing an adequate response to India's changing health needs, the recently promulgated National Health Policy (NHP) 2017, the country's leading health policy (which replaced the NHP 2002), omits to mention zoonoses as a major health concern and provides no guidelines for promoting cross-sectoral action. Clarity on engagement with the animal and/or environment sectors is also conspicuously missing from the policy (31).

Some national programs to control zoonotic diseases by NCDC (National Centre for Disease Control) include National Rabies Control Programme (NRCP), National One Health Programme for Prevention & Control of Zoonoses, and Programme for prevention and control of leptospirosis. NRCP was approved during 12th five-year plan in 2013 and had two components- human health and animal health. Human health component was rolled out in all the states and union territories of India while the animal health component was pilot tested in Haryana and Chennai, and it ended in 2017. It is odd that the animal component was only implemented in two states, and that it stopped so quickly, given that the only way to prevent rabies is to vaccinate animals and control animal populations. The activities completed during this include: training and capacity building, state guidelines and tech support, rabies and animal bite surveillance, lab strengthening, Information, education and communication (IEC) (33). Recently, National Action Plan for Dog mediated Rabies Elimination from India by 2030 was launched by NCDC. It was prepared on the basis of 5 major pillars: political will, intersectoral planning, sustained funding, community planning, coordination & review, and operational research with a mission to progressively reduce and ultimately eliminate human rabies in India through sustained mass dog vaccination and appropriate post-exposure treatment (34). The National One Health Programme for Prevention & Control of Zoonoses was also approved during the 12th five year plan and the activities undertaken in 2018-19 in this include IEC, intersectoral coordination, formation of state level zoonosis committees in 14 states, and technical support (35). Also, during 12th five-year plan the Govt. of India launched the Programme for Prevention and Control of Leptospirosis (PPCL) in the endemic states. Although the programme is still in its nascent stage, it has been able to sensitize the state Governments about the significant public health impact of the disease. The surveillance of the disease has been strengthened and cases and outbreak are regularly reported through Integrated Diseases Surveillance Project (IDSP) portal (36).

The existing policies in India acknowledge the importance of cross-sectoral collaboration among human-animal-environment interface for zoonosis control. However, many are unclear about the guidelines or practical steps needed to implement such engagement in daily life. Multi-sectoral convergence is a difficult, multi-layered process.

India's growing resistance problem and antibiotic use on the dairy farms

India has been called the "AMR capital of the world" (37) and the emergence of novel multi-drug resistant (MDR) organisms has led to many diagnostic as well as therapeutic challenges (38).

According to a scoping report on antimicrobial resistance in India published in 2017 (39), among Gram-negative bacteria, nearly half of all *Pseudomonas aeruginosa* isolates and more than 70% of *Escherichia coli, Klebsiella pneumoniae*, and *Acinetobacter baumannii* isolates were resistant to fluoroquinolones and third generation cephalosporins (39). India has also seen an increase in colistin resistance. Dual carbapenem and colistin-resistant *K. pneumoniae* bloodstream infections are linked to 69.3% mortality in humans (40). According to the ICMR (Indian Council of Medical Research) AMR surveillance network 2020, the overall proportion of methicillin-resistant *Staphylococcus aureus* (MRSA) in the human population was 41.4% (41) .

Poverty, illiteracy, lack of awareness about infectious diseases in the general public, and the inaccessibility to healthcare frequently prevent people from seeking medical guidance (45). This results in self-prescription of antibiotics without any information of the dosage or length of treatment from professionals. Due to a lack of appropriate diagnostic tools for determining the pathogen and its drug susceptibility, also many people who seek medical guidance end up receiving broad-spectrum antibiotics. The spread of MDR organisms in hospital settings is aided by low doctor-to-patient and nurse-to-patient ratios as well as a lack of infection, prevention and control (IPC) protocols. AMR is also made worse by the accessibility of over the counter (OTC) medications (38).

Antimicrobials are being used in abundance in the animal sector for treatment and prophylaxis as well as to increase productivity and promote growth, since the demand for animal products is rising day by day (7). There are many reports of milk samples across the country found positive for the presence of antibiotic resistant bacteria (12,13,42–44). When milk samples were analyzed to estimate AMR in livestock, 48% of Gram-negative bacteria found in cow and buffalo milk produced extended-spectrum β-lactamases (ESBL) in West Bengal, and 47.5% were oxytetracycline-resistant in Gujarat (45). Amongst the Gram-positive bacteria isolated from milk samples, 2.4% of *Staphylococcus aureus* were resistant to vancomycin in West Bengal (43) and 21.4% of *S. aureus* was methicillin resistant in Karnataka (46). A study from India, where the milk was sampled from cows suffering from mastitis, found co-infection of methicillin-resistant *S. aureus*, methicillin-resistant *S. epididymis* and extended spectrum β- lactamase *E. coli* (47). A review of AMR studies made in poultry reports the rate of ESBL producers to vary from 9.4% in Odisha to 33.5% in Madhya Pradesh to 87% in Punjab and the presence of *Salmonella* species in broilers to vary from 3.3% in Uttar Pradesh to 23.7% in Bihar, with

100% of *Salmonella* isolates being resistant to ciprofloxacin, gentamicin and tetracycline in Bihar and West Bengal (39).

There is still no data available that depicts a national picture quantifying the amount of antibiotics and the kind of antibiotics being used in the animal sector (48). The farmers often treat the sick animals on their own without consulting a veterinarian (4) and sometimes when a professional is not available they tend to consult a "quack" (a person not professionally trained to treat animals) (4,22). Smallholder farmers frequently wait until the situation has gotten serious and the animal has received numerous antibiotic treatments before consulting a veterinarian (2). Along with this, the withdrawal period is rarely followed and the milk from cows treated with antibiotics is often sold for human consumption (2,22). Some of the reasons that are leading to a rise of AMR in the animal sector include lack of awareness amongst the dairy farmers related to AMR, antibiotics, and withdrawal period, as well as lack of readily available veterinary services specifically in rural areas, easy and unregulated accessibility of antibiotics in the pharmacies, lack of diagnostic facilities and a heavy burden of infectious diseases (2,4,5).

Current policies and recommendations related to AMR

With the release of the National Policy on Containment of AMR in 2011, AMR-related policies were launched. In order to develop a plan to address the AMR issue, additional nongovernmental initiatives, like the Chennai Declaration, were also published (39). In April 2017, a comprehensive National Action Plan for Containment of AMR was launched (49). Below is the table giving a timeline of AMR policy related activities in India (22,39).

2010	Establishment of the National task force on AMR containment
2011	Publication of National policy on AMR containment
2011	Jaipur Declaration on AMR containment
2011	The Food Safety and Standards (Contaminants, Toxins and Residues) Regulations- Food Safety and Standards Authority of India (FSSAI)
2011	Establishment of the National Programme on AMR Containment under the Twelfth Five Year Plan (2012–2017)
2012	National Program on Antimicrobial Stewardship, Prevention of Infection and Control (ASPIC) by ICMR
2013	Establishment of a National AMR Surveillance Network by NCDC and ICMR
2014	Inclusion of antibiotics in Schedule H1 category to avoid non-prescription sales of Antibiotics
2016	Launch of the Red Line Campaign on Antibiotics to create awareness regarding rational usage of antibiotics
2016	Publication of National Treatment Guidelines for Antimicrobial Use in Infectious Diseases by NCDC
2016	National address by prime minister on the issue of antibiotic resistance in his Man Ki Baat (a radio program hosted by the prime minister of India) in August
2017	Publication of the National Action Plan for Containment of AMR and Delhi Declaration
2017	FSSAI released “Antibiotic Residues limits” in food from animal origin.
2019	The Ministry of Health and Family Welfare issued an order prohibiting the manufacture, sale, and distribution of colistin and its formulations for food-producing animals, dairy, poultry, aqua farming, and animal feed supplements.

The effectiveness of these policies and programs in AMR containment or consumption of antimicrobials remains unknown. It is also unknown how strictly the adopted policies are being followed. Antibiotics, for instance, are still available OTC despite being on Schedule H1. Schedule H1 is a list which has 46 drugs comprising third and fourth generation cephalosporins, carbapenems, newer fluoroquinolones and first and second line antitubercular drugs. These drugs should not be sold without a valid prescription and the chemist needs to maintain a sales record for these drugs (50). The implementation of these regulations has been challenging. Key problems that affect implementation include funding to undertake and sustain proposed activities, efficient intersectoral coordination, and technical stewardship across the country (38). Lack of a separate financial allocation remains the greatest challenge for the implementation of NAPs and/or State Action Plans as health comes under the purview of state governments and because they are usually burdened in managing the finances for many other schemes, the focus and fund allocation toward newer health initiatives is limited (49).

Aims of the thesis

This thesis aims to generate information on beliefs, practices, and knowledge regarding antimicrobials, AMR, milk safety, hygiene, and zoonotic diseases. It also aims to raise awareness and better understand the factors that contribute to improved knowledge and practices on AMR and zoonotic illnesses in the dairy sector.

Specific aims

1. To describe the knowledge and practices among the dairy farmers, milk vendors, veterinarians, and other veterinary workers, related to milk safety, AMR, antibiotics, common zoonotic diseases, and their transmission from animals to humans.

2. To identify and describe the practices among the dairy farmers regarding their antibiotic use.

3. To analyze factors associated with presence of antibiotic residues in milk.

4. To pilot and evaluate an intervention for reduction of public health risk related to AMR and zoonotic diseases in the dairy farmers as well as other stakeholders including veterinarians.

Methods and materials

Definitions

In this thesis, in *study 1*, the dairy farms are classified into small scale, medium scale and large scale based on the number of milking animals in the farm. The small-scale dairy farms have 1-3 dairy animals, the medium scale dairy farms have 4-9 dairy animals and the large-scale farms have more than 10 dairy animals.

In *study 2*, there are two types of veterinary practitioners: a) veterinarians who are veterinary professionals and are responsible for the treatment of animals, and b) Para-veterinarians (paravets) who typically undergo training for one or two years to obtain a diploma and assist veterinarians in vaccination, artificial insemination in dairy animals, pregnancy diagnosis and minor treatments. They are basically the frontline veterinary workers (4).

The term "quacks" in *study 2,* is used for the people who are not professionally trained in veterinary and animal sciences but still treat animals and give antibiotics to the dairy farmers.

Study sites

For study 1, data from a cross-sectional survey in two Indian states, Assam, and Haryana, were analyzed. A multi-stage selection process had been followed. The district selection was guided by Animal Husbandry and Veterinary Department officials regarding the district's potential for dairy development (low, medium, and high). Accordingly, the three districts Kamrup (metropolitan), Golaghat, and Baksa were selected for Assam, and Karnal, Kaithal, and Bhiwani for Haryana (Figure 1). From each district two community development blocks (CDB) were randomly selected and under each CDB, four villages were randomly selected. For the farm survey in each village, ten households were selected randomly from the list of farming households having dairy animals (cattle or buffalo) in each selected village. The sampling frame was guided by key informants such as local non-governmental organizations and some leading farmers.

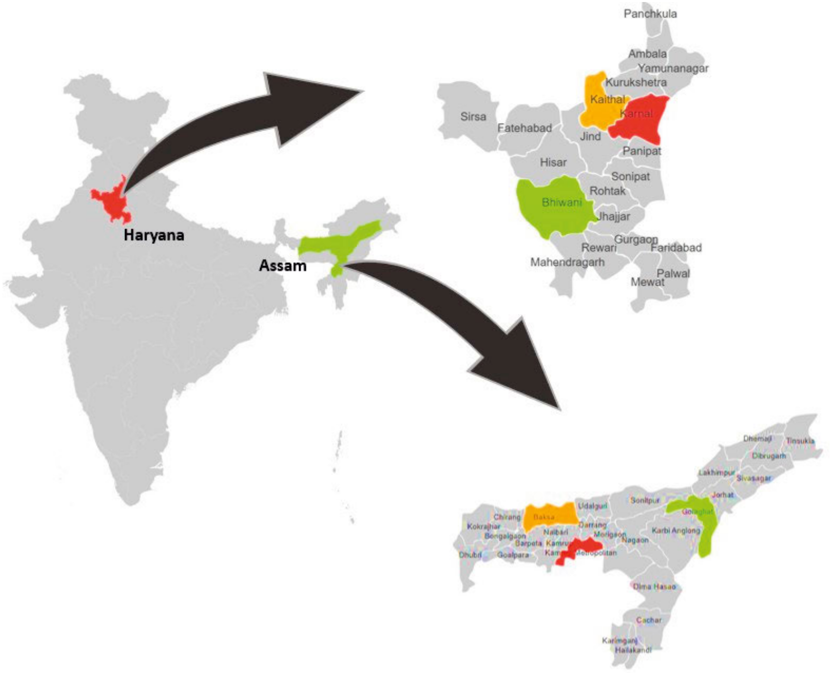

Figure 1. Map of India with the highlighted study states and the districts in each study state (5)

For study 2, four Indian states were included: Guwahati (in Assam), Karnal (in Haryana), Bangalore (in Karnataka), and Kolkata (in West Bengal) (Figure 2). In Guwahati, Karnal and Bangalore a total of eight villages (four urban and four rural) were included in the study. In Kolkata, four villages were selected (two rural and two urban). Villages in Karnal and Guwahati had randomly been selected to participate in the farmer and vendor survey described above (51,52). In addition, two more regions Bangalore (Karnataka) and Kolkata (West Bengal) were added to increase the number of states. In Bangalore and Kolkata, a list of villages near the district headquarters was prepared; the ones included in the study were randomly selected from this list.

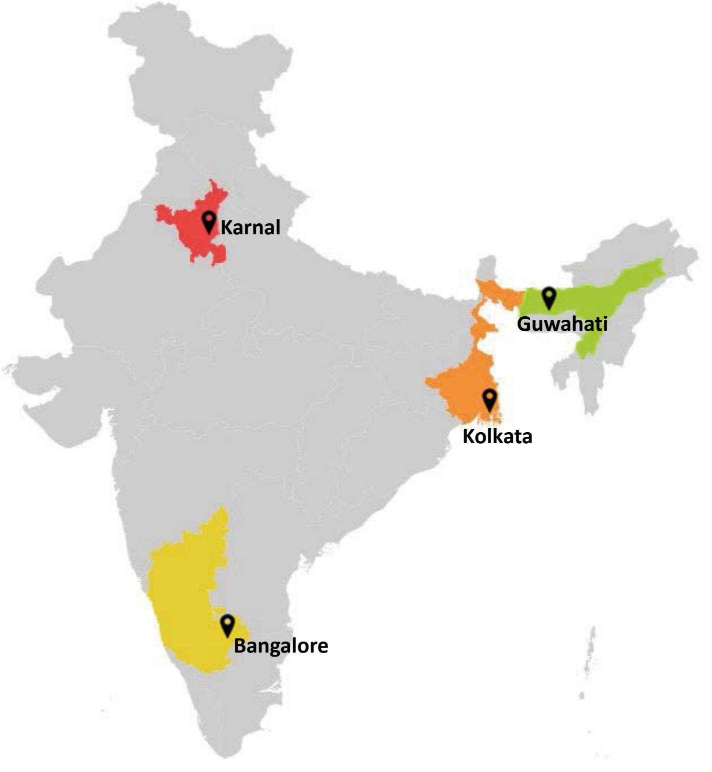

Figure 2. Map of India highlighting the four study states pointing out the study region (4)

Table 1. Summary of applied methods and materials

	Study 1		Study 2	
Components	**1**	**2**	**1**	**2**
Study design	Cross-sectional survey		Qualitative study	Cross-sectional survey
Years of data collection	2016-2017	2017	2018-2019	
Study population	Dairy farmers	Milk vendors	Dairy farmers, Veterinarians	
Study sites/states	Haryana and Assam		Haryana, Assam, Karnataka, and West Bengal	
Sample size	491	244	28 focus group discussions (FGDs) and 53 key informant interviews (KIIs)	274 dairy farmers and 51 veterinarians
Data collection methods	Farmer KAP survey, antibiotic picture cards, collection of milk sample from each farm	Vendor KAP survey, milk sample purchased (if available)	Focus group discussions with the dairy farmers and key informant interviews with the veterinarians, paravets	KAP survey with farmers and veterinarians
Lab analysis	DPA test, strip test (NDRI), Charm rosa method	Antibiotic disc diffusion testing	None	
Data analysis	Fisher's exact test, Cronbach's alpha for internal consistency and multivariable linear regression	ANOVA (analysis of variance), Chi-square	Qualitative data analyses via listing, categorization of codes and generation of themes, sub-themes	Chi-square, Cronbach's alpha, Univariate linear regression, and Multivariable linear regression

Sample size

In study 1, for the farmer survey, 491 dairy households were selected (242 in Assam and 249 in Haryana) and 491 milk samples were tested for the presence of antibiotic residues. For the vendor survey, 244 (122 in Assam and 122 in Haryana) vendors were interviewed, and 124 milk samples were analyzed for the presence of antibiotic resistant bacteria.

In study 2, in component 1: Twenty-eight focus group discussions (FGDs) were conducted with the dairy farmers and 53 key informant interviews (KIIs) were done with the veterinarians and paravets. In the follow up, 274 dairy farmers and 51 veterinarians and paravets participated in the survey.

Study design and data collection

For study 1, data was analyzed from the earlier cross-sectional survey to assess the knowledge and practices of the farmers and vendors related to antibiotics, AMR, milk hygiene and safety. The study had two components including analyzing the data from a farmer survey and a vendor survey. In the farmer survey, which had been done in April 2016-March 2017, farmer KAP regarding antibiotics and their ability to recognize pictures of locally available antibiotics was combined with laboratory analyses of milk samples taken from the surveyed farms to detect any antibiotic residues. For the vendor survey, the same villages that were in the farmer survey had been visited during October-November 2017. All the milk vendors identified at the time of the visit and who gave consent had been interviewed regarding their knowledge and practices on antibiotics, milk safety and hygiene. Also, a milk sample (if available) was purchased and tested for the presence of any antibiotic resistant bacteria.

Study 2 had two phases. First, a qualitative study with an intervention, and a follow-up survey. In the first component, that was performed in September-October 2018, FGDs were conducted with the dairy farmers and veterinarians, paravets were interviewed. A timetable/schedule to visit each village was made beforehand. The timetable was relayed to village veterinarians, who, through paravets, arranged a site and checked with farmers to confirm their availability. They helped coordinate village gatherings; 10–20 farmers were invited. To participate in the study, farmers needed to have at least one dairy animal (cow or buffalo). The conversations were guided by a FGD tool providing questions and probes. The meetings took place in a large room either at the village council office or the village school, or the residence of a local farmer. A moderator guided the conversations, assisted by a second person who took notes and handled the audio recording equipment. The farmers were seated in a semicircle, and the discussion was conducted in their native language. Prior to the start of the discussions, the moderator had an introduction session in which he introduced himself to the farmers and explained the objective of the meeting. Also, he took a verbal consent for recording the discussion. Every participant was encouraged to share their thoughts and actively participate in the conversation. The meetings lasted for an average of 1.5-2 hours. The veterinarians and one or two paravets in each village were interviewed. KII instruments with key questions and probes were developed to facilitate the interviews. Mostly, the interviews were conducted at the local veterinary hospitals/dispensaries. The interviewer made a formal introduction, explained the reason for the interview, and obtained permission to proceed. After seeking consent, the conversation was audio recorded and notes were taken. Approximately 1–1.5 hours were spent on each interview.

Immediately after the discussions, each participant was provided with the intervention material that was prepared in their local languages and briefly explained to them by the moderator. Villages were randomly assigned to one of four intervention options (Figure 3). In Guwahati, Karnal, and Bangalore, where eight villages were included, two villages (one rural and one urban) were considered for each intervention. In Kolkata, just one village was considered. Different extension material was delivered to villages in intervention groups 1, 2, and 3, but none was given to villages in the 4th intervention group. Depending on the intervention, participants learned about animal health and disease prevention, including biosecurity (groups 2 and 3), antibiotic usage in dairy animals (groups 1 and 3), antibiotic residues in animal-source foods, and AMR risk in humans (group 1 and 3). Groups 2 and 3 (disease component) focused on mastitis, brucellosis, leptospirosis, and Q fever (their causes, manifestation, impact, and control).

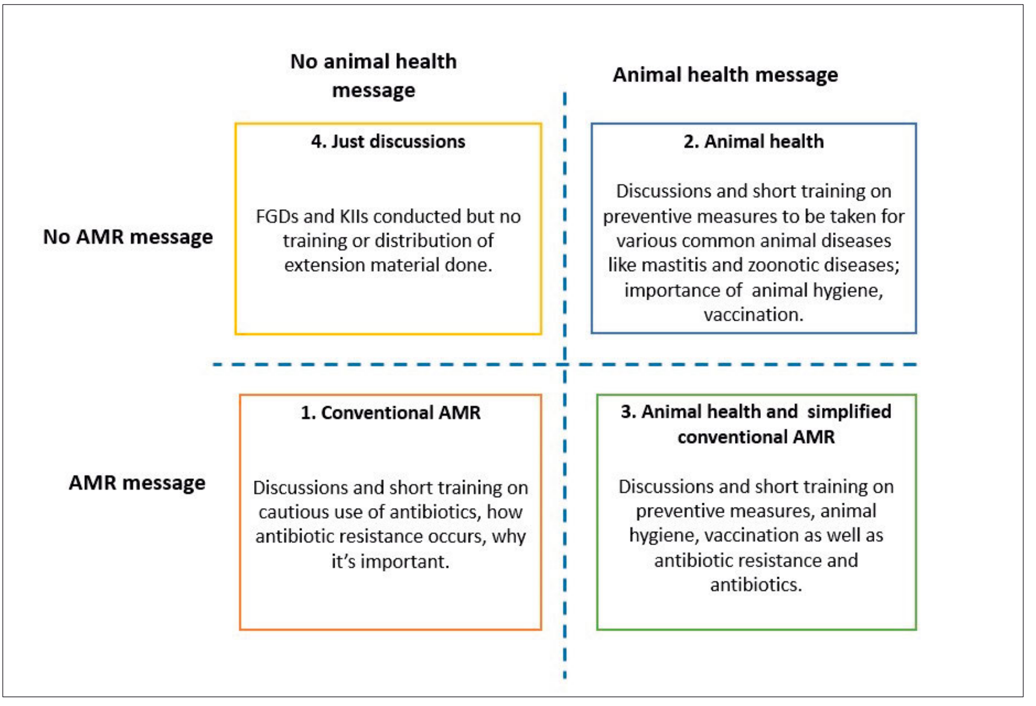

Figure 3. Our four intervention approaches (Paper 3)

The follow-up survey was conducted in November-December 2018 to evaluate the efficacy of the above interventions. Two surveys were designed, one for dairy farmers and the other for veterinarians and paravets. Data were collected from the same villages. Any farmer, veterinarian, and paravet was allowed to participate, including both those who had previously participated in the discussions (FGD and KII) as well as some who had not participated, but the questionnaire included a question on who had participated or not.

Laboratory analysis

In study 1, for the farmer survey, screening of milk samples for antibiotic residues was conducted in two steps at the National Dairy Research Institute (ICAR-NDRI). First two semi-quantitative tests were used, dipicolinic acid (DPA) test and a strip test, developed by ICAR-NDRI, India. Positive results were further tested by the Charm Rapid One Step Assay (Rosa) lateral flow strips (Charm Sciences Inc., Lawrence, MA, USA) to identify which antibiotic groups that were present, and to evaluate if samples exceeded the maximum residue levels set by the European commission of the European union.

For the vendor survey in Study 1, the milk samples were tested for the presence of antibiotic resistant bacteria using antibiotic susceptibility testing at

National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI). The isolated bacteria from these milk samples were screened for AMR bacteria using an antibiotic disc diffusion testing as per Kirby Bayer's method (53) and following the Clinical and Laboratory Standard Institute guidelines.

For the purpose of this thesis, the lab results from both these surveys, were then interpreted and used further in data analyses.

Data analyses

Data was entered in Microsoft Excel and analyzed using ‘R’ statistical software and STATA 14.0. For the farmer survey in study 1, descriptive data (survey data) for all farms was combined with laboratory results corresponding to the milk samples. Initial univariable analyses were conducted using Fisher’s Exact Test for associations between different categorical variables and farm size variable that was categorized based on the no. of milking animals per herd to small scale (1-3 milking bovines), medium scale (4-9 milking bovines) and large-scale farms (>10 milking bovines). For knowledge, a score was allotted to farmers’ responses in the questionnaire. A score of ‘1’ was assigned to a correct answer and a ‘0’ score assigned for the wrong answers. The total mean knowledge score was then calculated for each respondent. Internal consistency was measured using Cronbach alpha. A multivariable linear regression model was built in STATA to test correlation of knowledge score with farm size, state, and gender.

The data of the vendor survey was entered in Microsoft Excel and analyzed using STATA 14.0. Descriptive analysis of all vendors was carried out, followed by analysis of variance (ANOVA) to test for association between the type of vendors and different variables like gender, education, and amount of milk sold. Secondly, for the vendor milk samples which were tested in the lab for presence of resistant bacteria, initial univariable analysis was conducted to check associations between categorical variables like age, gender, education, milk sold, type of vendor and the presence of AMR bacteria in milk samples.

For study 2, in the first component, qualitative data analysis was carried out for the FGDs and KIIs. The audio recordings and field notes from FGDs and KIIs were translated, and the resulting transcripts analyzed as described below:

- Listing of codes: transcripts were read multiple times, and this ensured a better understanding of the data. Participant response was enlisted, and codes generated for each of the responses. In the process, important statements, or quotes, with their references, were identified and extracted.
- Categorization of codes: Codes with similar or comparable meanings were merged and placed under one category.

- Generation of themes and sub-themes: The categories representing a similar idea came under one core-theme. Sub-themes were generated under each core theme. The responses were suitably placed for analysis under the core themes and sub-themes.

For the follow up survey, the data was entered into Microsoft Excel and checked twice for typographical errors, missing entries, and other problems. For data analysis, STATACorp Ltd.'s Stata/SE 15.1 software was used. Each farmer received a score based on how well they responded to queries on the usage of antibiotics and AMR. Each question received a score of 1 for the right response, and a score of 0 for the wrong response. We calculated proportions and frequencies to describe farmer demographics, knowledge, attitude, and practice related variables. A Chi-square test was used to check for associations between knowledge indicators on antibiotics, AMR, survey takeaways, and intervention approach. The knowledge indicators' internal consistency was measured using Cronbach's alpha. First, a univariable linear regression was done to assess the association between our continuous outcome-knowledge score and intervention approach, FGD participation, and independent variables including gender and education. The variables with a significant association ($p < 0.05$) were kept in the multivariable linear regression model. Multivariable linear regression was used to assess the association between farmer knowledge and intervention type, FGD participation, and gender. For the veterinarian and paravet data, descriptive statistics were performed, and bivariate analysis/ approach wise classification was done for the veterinary professionals (veterinarians and the paravets) related to their perspective about AMR, about how they will explain AMR to the dairy farmers and things remembered by them from the KII discussions. A $p<0.05$ was considered statistically significant.

Ethical considerations

For study 1, for the farmer survey ethical approval was granted by the Institutional Research Ethics Committee (IREC) of the International Livestock Research Institute (ILRI) on 21 September 2015 (No. ILRI-IREC2015-12). And for the vendor survey ethical approval was granted by the IREC of ILRI on 27 February 2017 (No. ILRI-IREC2017-05) and approved by the collaborating institutes within the Indian Council of Agricultural Research (ICAR). At the time of interview, signed, informed consent was obtained from all participants.

Study 2 was approved by the ILRI IREC (ILRI-IREC 2018–25). All the participants (farmers, veterinarians, paravets) were informed about the study and consented to participate and for the data to be published. Verbal informed consent was obtained prior to the group discussions and written consent was obtained prior to the filling of questionnaires in the follow up survey.

Results

Knowledge and practices related to antibiotics, AMR

Our results showed that the knowledge level and awareness of the dairy farmers related to antibiotics or AMR was (quite) low. In study 1, in the farmer survey, 39% (193/491) of the dairy farmers responded that they have heard about antibiotics and only 11% (55/491) could recognize antibiotics on the picture cards of locally available antibiotics, that were shown to them. Out of these 11% of farmers who recognized antibiotic picture cards, 47% had responded in the questionnaire that they had never heard of antibiotics. The recognition of antibiotics by farmers on picture cards did not appear to match their understanding of antibiotics. Only 2% (8/491) of the dairy farmers said that they had heard of “withdrawal period.” In study 2, the results from the focus group discussions with the dairy farmers revealed that they were not aware of the names of any antibiotic or could clearly express what an antibiotic is. Also, they were not aware of any health risks associated with the use of medicines in animals or presence of antibiotic residues in the milk or failure to observe withdrawal periods. A few farmers in the qualitative survey knew about drug withdrawal periods, but they still used milk from animals on antibiotic treatment as they could not afford to waste it:

"If treatment is going on, then we don’t consume the milk, but we sell it.”- FGD (Kolkata)

Regarding practices, it was observed that the dairy farmers used antibiotics on the animals without seeking a veterinarian's advice. Discarded antibiotic packets were found in some of the dairy farms during on farm inspection done in study 1. Various reasons given by these farmers for administering the antibiotics to cattle included farmers perception of cows with a fever, mastitis, diarrhea, or to increase milk production. Results from FGDs also revealed that the dairy farmers gave antibiotics to the animals without consulting a veterinarian. They used old prescriptions to buy the antibiotics and determine the dosage. In some cases, they also sought advice from the local pharmacy person (not trained to prescribe antibiotics).

"I notice the sign and symptoms first and try to treat with home remedies available at our homes or go to store/pharmacy for medicine. Then also if problem persists, I call veterinary professional/doctor."- FGD (Guwahati)

Some of them took help from a "quack" or a "village doctor" (an unqualified person who claims to have veterinary knowledge and treats animals illegally). During one of the FGDs, a large-scale dairy farmer who had around 50 dairy cows and buffaloes on his farm said:

"I am a dairy farmer and it's been 10–15 years in this field, so first I treat my animals by giving antibiotics but if the problem persists then only, I call the doctor."- FGD (Karnal)

The results of the survey of milk vendors in study 1 showed that, like the dairy farmers, the milk vendors didn't know much about antibiotics or the milk withdrawal period. Some of them who said they knew about antibiotics could not give a clear definition of what an antibiotic was.

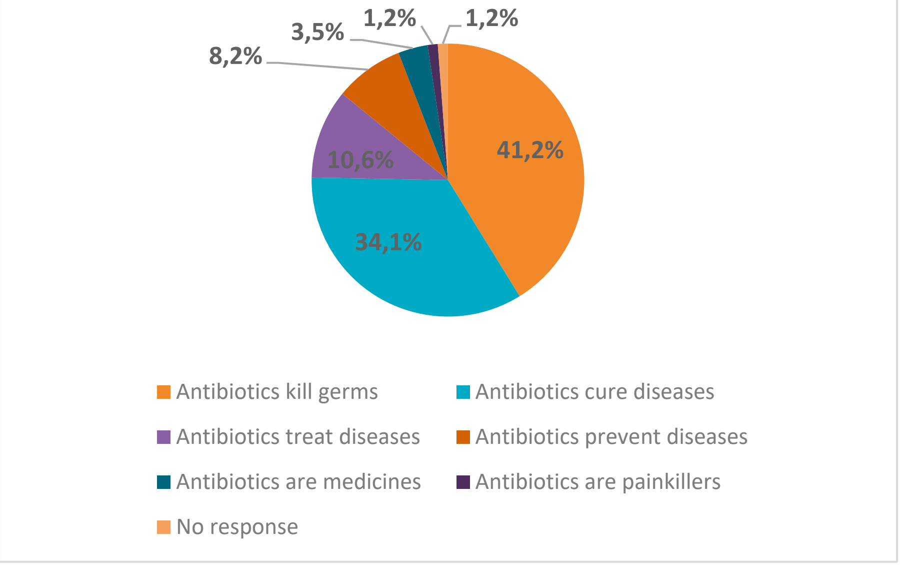

Figure 4. Various definitions given by the vendors who agreed to know about antibiotics

Not all of the paravets who were interviewed could give a precise definition of either antibiotics or antimicrobial resistance, despite the fact that they all appeared to be familiar with the causes of antibiotic resistance and the idea of antibiotic resistance. They relied upon the drug marketing agents to know about the effectiveness of antibiotic. Most of the paravets agreed to treat animals with antibiotics and only a few of them consulted the veterinarian before prescribing an antibiotic.

"It is not fixed actually. Sometimes I prescribe, the other times I don't. It depends upon the case. If the animal is ill, it is mandatory to give an antibiotic."- KII (Paravel, Karnal)

Antimicrobial resistance was a topic familiar to the veterinarians. Some of them sent samples for laboratory testing before prescribing antibiotics, but others acknowledged that this was not always feasible due to a lack of accessible diagnostics. They did hold the dairy farmers who treat animals on their own; the "quacks" and the paravets who administered antibiotics without consulting them responsible for the escalating rates of AMR in the livestock sector.

"Yes, we are all responsible because if you talk about farmer, they should consult us regarding medicine and drug i.e., mechanism, side-effects, residue and how long it will act but they go to pharmacy and directly buy those drugs. The main problem here, are the medical representatives who go to farmers directly and sell those antibiotics and other medicine at 20%-30% discounted rates. Secondly, are the quacks that without knowledge go to administer injections. All rules and regulation are there but no one is following. Drug controllers are not able to reach those areas. "- KII (Veterinarian, Guwahati)

Presence of antibiotic residues and antibiotic resistant bacteria

When evaluated with a strip-based assay technique, 40 samples out of 491 dairy farm milk samples tested positive for antibiotic residues (8%, 95% confidence interval (CI) 6-11%). Antibiotic positive samples were found to be more prevalent on large-scale farms. 29 (5.9%, CI 4-8%) positive samples exhibited levels of residues that were higher than the maximum residue limit (MRL) set by the European Commission of the European Union (54).

Table 2. The maximum residue limit (MRL) set for various antibiotics by European commission and no. of milk samples exceeding MRL

Antibiotic group	**MRL in milk set by European commission**	**No. of milk samples exceeding MRL**
Beta-lactam antibiotics	4 µg/kg	3
Tetracycline/chlortetracycline/oxy-tetracycline	100 µg/kg	4
Sulphonamides	100 µg/kg	5
Novobiocin	50 µg/kg	17
Macrolides (Erythromycin)	40 µg/kg	12

In total, 124 milk samples from vendors were tested for the presence of antibiotic resistant bacteria, with 64.5% (80/124, CI 55%-72%) having presence of at least one bacterial isolate resistant to at least one antibiotic. Out of the samples that tested positive, 83.7% (67/80, CI 73%-91%) were from the raw milk vendors and 16.2% (13/80, CI 8%-26%) were from the pasteurized milk vendors.

Veterinary consultation

The consultation pattern of the dairy farmers revealed a lack of well-developed veterinary infrastructure in our studies. In study 1, 12 % (58/491) of the surveyed farmers reported never having a veterinary visit on their farm and most of these were the small-scale dairy farmers. In study 2, during the FGDs it was found that the consultation behavior of the dairy farmers was related to the availability of veterinarians in the area. Three regions- Karnal, Kolkata, Guwahati- had low access to veterinary services and therefore, the dairy farmers used old prescriptions from the veterinarians to buy antibiotics, took help from the local pharmacist, used home remedies to treat sick animals or consulted "quacks." In one of the study regions the veterinary services were readily available due to a milk cooperative called "Karnataka milk federation" (KMF) and the dairy farmers always consulted a veterinarian when the animals got sick.

"I always get help from KMF for the treatment of my animals. The doctor comes on time and gives medicine." - FGD (Karnataka)

In the regions where the veterinarians were not readily available, the dairy farmers mostly relied upon "quacks" and paravets. They only tried to reach out to a veterinarian after the animals failed to respond to any treatment.

Knowledge and perceptions related to zoonotic diseases, hygiene, and safety

Results from FGDs revealed that the dairy farmers were not aware of the term "zoonotic" but were aware of the fact that diseases might occur in humans when they get in contact with sick animals. A few of them talked about rabies, brucellosis and tuberculosis while discussing.

"Yes, abortion occurs, and it happens because of disease Brucellosis. And we dispose the aborted material in river."- FGD (Karnal)

However, most of them did not take any particular precautions while handling the sick animals or aborted fetus. The results also revealed that in abortion cases, the dairy farmers wrapped the fetus in a jute bag, and disposed it off, by either burying or throwing it in a river.

"I don't think we can get infection from animals if we keep the shed clean with bleaching powder and wash our hands"- FGD (Karnataka)

The farmer survey in study 1 also highlighted lack of training amongst the dairy farmers. Only 6% (CI 4–8%) of the surveyed farmers had received any training in livestock management, animal diseases and most of them were large-scale farmers.

The interviews with the veterinarians and the paravets showed that they were well aware of the prevalent zoonotic diseases including brucellosis, rabies, tuberculosis, and bird flu. Some of them also mentioned anthrax. They took the required precautions while handling the sick animals and always informed the farmers as well.

"I always use gloves when i check a sick animal and wash my hands after treatment so that i don't get any infection. I tell the farmer to wash hands too."- KII (Paravet, Kolkata)

The majority of the vendors surveyed in study 1 dealt in raw milk, and their handling and storage practices—such as not keeping the milk refrigerated between buying it from the farm and selling it—were identified as being risky. Only a very small number of the examined vendors had any training in hygiene and food safety, and their perspectives and understanding on milk safety were found to be inadequate. Nearly every single one of them did not adhere to the national milk safety standards.

Effectiveness of the interventions in the dairy farmers: follow-up survey findings

In total, 274 farmers were interviewed during the follow-up survey and most of them had participated in the previous FGDs followed with training for three of the groups. The majority (65.8%) of these farmers in the follow-up responded that antibiotics are used to treat bacterial infections, with many of them (53.7%) agreeing that antibiotic residues are very likely to end up in milk. Most (62%) of the dairy farmers agreed that bacteria infecting animals can become resistant and 45.1% agreed that resistant bacteria are very likely to grow in the animal and spread to people.

The awareness level related to zoonotic diseases was also found to be improved with 47% of them aware that animals can transmit the diseases to humans and various modes of transmission - direct contact (43.6%), inhalation (45.4%), ingestion (34.4%) and contact with animal products (55.7%). They were also found to be aware about the various preventive and control measures that must be followed while handling a sick animal. Almost all of them (96.4%) rated handwashing as extremely important; many (89.8%) mentioned discarding everything that comes from a sick animal. They also talked about isolating sick animals and use of gloves.

The dairy farmers were also found to be familiar with the risks involved with treating animals on their own or using antibiotics without consulting a veterinarian. The majority of respondents (84.3%) agreed that it's always best to call a veterinarian, so the animal gets proper care. Overusing antibiotics can cause future problems, according to 69.7% of the farmers. However, one third (34.7%) mentioned that they can't throw away milk while the animal is being treated; they need to sell it for money, and it's not too bad to ingest.

The multivariable analysis revealed that the knowledge score of the farmers was higher in the ones who had previously participated in FGDs ($p < 0.05$), received intervention in approach 2-animal health ($p = 0.03$), approach 3-animal health and AMR ($p = 0.01$).

Discussion

This thesis provides a glimpse of the major stakeholders involved in India's dairy value chain, as well as their knowledge, behavior, and perceptions regarding antibiotics, AMR, milk handling, and prevalent zoonotic diseases. Dairy farming is a significant source of livelihood and dairy farmers with less than five milking cows or buffaloes dominate the Indian dairy industry. Dairy is mostly an informal industry in India, with very few people consuming packaged milk and most buying milk from the raw milk vendors. The veterinarians are responsible for the treatment of sick animals, while the paravets are the frontline veterinary workers involved with minor treatments, vaccination of animals etc.

The key findings of the thesis indicate that the dairy farmers were unaware of antibiotics and AMR. A novel finding which has not previously been emphasized in the literature is the dependence on "old prescriptions" a form of semi-compliance, with regulations. They also depend on the local pharmacy to determine the names and dosage of the medications. These results are quite similar to other studies that reveal a lack of understanding of antibiotics or AMR amongst the dairy farmers and over the counter sales of antibiotics without prescription (55). Dairy farmers were also unaware about drug withdrawal periods and any health risks related with the use of antibiotics to treat animal diseases or the presence of antibiotic residues in milk. A few of them who knew about withdrawal period still consumed or sold milk while the animal was undergoing treatment as they could not afford to waste it. Similar results are seen in other Indian studies which reveal that because of the financial loss caused by the rejected volumes, dumping milk may not be an option for certain producers (2,22,56). Consideration should be given to providing incentives that encourage compliance while protecting the livelihoods of farmers.

Although not many, some milk samples from these dairy farms contained antibiotic residues, and discarded antibiotics were found on the farm's premises indicating their use. Several studies from India report contamination of milk with antibiotic residues (11,57). Indeed, this is a cause for concern and a major threat to public health.

The majority of dairy farmers in our study believed in the advice of the veterinarians, but due to a lack of enough veterinary facilities in the area, they turned to other options like self-treating animals or consulting a "quack" or paravet for treating their animals. Similar outcomes are seen in other Indian studies where an extreme lack of veterinarians prompted irrational antibiotic use among dairy farmers and informal prescribers (quacks) (2,58,59). Therefore, it is imperative that veterinary human resources be strengthened. Several factors that contribute to antibiotic use and antimicrobial resistance in dairy animals are shown in figure 5 below.

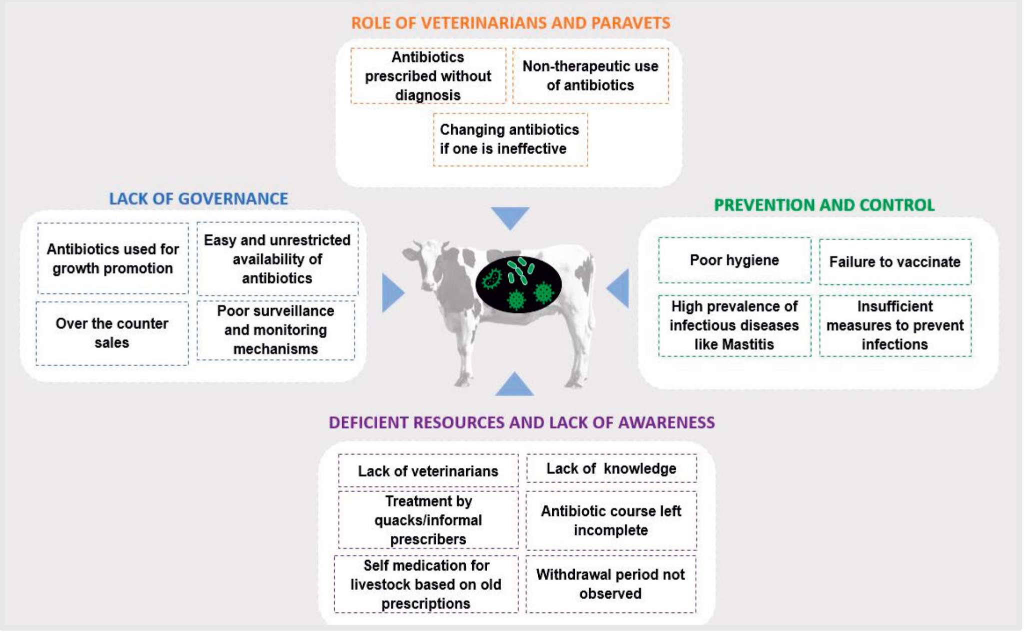

Figure 5.Factors responsible for antibiotic use in dairy animals

Like the farmers, the milk vendors surveyed in the study displayed low awareness related to antibiotics or withdrawal period. Also, the milk samples collected from these vendors had a high prevalence of antibiotic resistant bacteria. Similar results have been highlighted in previous studies where milk samples from the informal milk traders were found positive for the presence of antibiotic resistant bacteria (60). Our results also highlight that the milk vendors did not comply to the national milk safety regulations and had low knowledge about milk safety and hygiene. Some other studies have revealed as well that three-quarters of the milk that is sold in the Indian markets is through informal chains where compliance with safety standards is limited and risk of contamination is very high (61). While training might be an effective strategy to improve the awareness levels of the vendors regarding milk safety and hygiene, it is necessary to think about other interventions that will make it more practical and feasible for them to follow certain hygienic standards.

As per our results, both the veterinarians and paravets were quite aware about antibiotics and AMR. Although the paravets could not clearly define an antibiotic or antimicrobial resistance, they appeared to be aware of the causes of why antibiotics might stop working and the idea of antibiotic resistance. We also found that often the paravets were treating animals with antibiotics without consulting a veterinarian and this was mostly in the regions where the veterinarian was not readily available. Other studies have also highlighted that the paravets are preferred by the smallholder dairy farmers as they take less time to reach the farm, are readily available, charge less consultation fee and are willing to serve in rural areas (62). Clearly, the veterinary infrastructure needs to be reinforced with more veterinarians readily available in rural regions as well.

The veterinarians and paravets were quite aware about the zoonotic diseases and took necessary precautions while handling sick animals contrary to the farmers who were less aware about the zoonotic diseases and the necessary precautions to take while dealing with sick animals. Other studies have also revealed the same results where the knowledge of zoonotic diseases amongst dairy farmers of India is lacking, and they were mostly not aware of the risk of contracting zoonotic pathogens from consuming contaminated raw milk, meat or eggs (63). Despite the fact that India's government has put in place numerous programmes to combat diseases, zoonotic diseases are still not given the highest attention despite being extremely common.

Our intervention study did reveal that mere discussions about common animal diseases, preventive measures and antibiotic use with the dairy farmers enhances their knowledge level. This is an important finding as it suggests relatively low cost and hence scalable interventions could have benefits. It has been indicated in numerous studies that there is a pressing need for regular educational programmes to teach farmers about antibiotics, sensible drug use, and resistance, as well as about alternatives like vaccination and preventative medicine (2,64). Improved understanding among all stakeholders is essential to bring a change, therefore regular trainings and awareness efforts are essential, but they are only a piece of the puzzle. Farmers should be incentivized to produce safe milk, vendors should be likewise motivated to be aware of and adhere to certain hygiene requirements, and consumers should insist on safer milk from retailers and producers. A more robust veterinary infrastructure, with veterinarians easily accessible to smallholder dairy producers in remote areas, is needed. Although, both veterinarians and paravets were found to have adequate knowledge of antibiotics and AMR, they were unable to explain the concept to the farmers appropriately. Some of them even believed that the farmers wouldn't follow, thus there was no need to explain it to them. Just discussing things with farmers does bring a knowledge change and therefore, it is necessary to provide regular trainings that instruct veterinarians, paravets on how to advise farmers effectively.

Even though we did get interesting and novel results, the studies have several limitations. Since these studies were performed only in a few villages of certain regions (albeit selected purposively as information-rich comparisons), the results are not representative of the whole country and more studies with larger scopes need to be organized to know the exact situation. There might be a possible bias because the surveyed participants felt obliged to give an answer that would be viewed favorably (social desirability bias). For example: the veterinarians might say it was inappropriate to prescribe antibiotics without diagnosis but in fact do this in the field. In a similar vein, farmers might be more likely to report veterinarian's errors and less likely to report their own mistakes. To get more insight, we did try using a mixed method approach where we did both quantitative surveys as well as qualitative discussions, and, along with that, inspected the farms as well as interpreted the laboratory findings. But again, this was done only in limited areas and future studies are required to see if these methods actually work when dealing with the complexities of India's informal dairy value chain.

Conclusion and future perspectives

The inappropriate use of antibiotics on dairy farms is exacerbated by a number of factors as depicted in this thesis. It is extremely difficult to establish a baseline for antibiotic consumption on the dairy farms. Lack of readily available veterinary services was identified as one of the primary causes leading to an irrational use of antibiotics by dairy farmers or paravets or “quacks”, and enhancing availability of, and access to, animal health services would address this problem. In addition, we discovered that there is a lack of training programmes for smallholder dairy farmers and informal milk vendors on the fundamentals of milk safety, cleanliness, preventive measures, antibiotics, AMR, etc. Our results highlight that regular discussions improve the awareness levels and therefore, focus should also be there on conducting frequent training programmes related to basics of milk safety, hygiene, preventive measures, prevalent zoonotic diseases, antibiotics etc. to improve awareness amongst these stakeholders who hold a major chunk of India’s dairy sector.

The thesis provides evidence on some of the drivers that, if appropriately tackled, could resolve the issue of antimicrobial resistance (AMR) in the livestock sector. The policymakers need to design interventions that effectively reduce the sub-optimal use of antibiotics by the dairy farmers keeping in mind that these interventions are easy to adopt and do not harm their livelihoods. The milk vendors should be made aware of the existing regulations and milk safety standards. A rigorous monitoring and evaluation system must be developed to see if the stakeholders comply to the existing regulations. Policymakers are responsible for addressing the gaps/barriers that impede compliance with the regulations and identifying potential remedies. Despite the fact that the veterinary services have to be made more accessible to the dairy farmers, frequent trainings should be provided to both veterinarians and paravets on how to facilitate a behavioral shift in farmers when it comes to adoption of basic preventive measure to avoid zoonotic infections or following withdrawal periods or not self-treating the sick animals. The benefits, costs and any unintended costs of these actions should be assessed, and initiatives modified accordingly.

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