












RESEARCH ARTICLE

Veterinary antimicrobial stewardship in coastal Karnataka: A mixed-methods district-level assessment of prescribing practices, system gaps, and One Health implications



Ninu P. Mathew¹ , Unnikrishnan Bhaskaran² , Muralidhar D. Varma³ , Robert A.C. Ruiter⁴ , Vandana Kalwaje Eshwara¹ , Girish Thunga⁵ , Asha Kamath⁶ , Vani Lakshmi R⁷ , Jagnoor Singh Sandhu⁸ , Shankar Shetty⁹ , and Chiranjay Mukhopadhyay¹ 

1. Department of Microbiology, Kasturba Medical College, Manipal Academy of Higher Education, Manipal, India.
2. Department of Community Medicine, Kasturba Medical College Mangalore, Manipal Academy of Higher Education, Manipal, India.
3. Department of Infectious Diseases, Kasturba Medical College, Manipal Academy of Higher Education, Manipal, India.
4. Department of Work & Social Psychology, Maastricht University, Maastricht, the Netherlands.
5. Department of Pharmacy Practice, Manipal College of Pharmaceutical Sciences, Manipal Academy of Higher Education, Manipal, India.
6. Department of Applied Statistics and Data Science, Prasanna School of Public Health, Manipal Academy of Higher Education, Manipal, India.
7. Department of Health Technology and Informatics, Prasanna School of Public Health, Manipal Academy of Higher Education, Manipal, India.
8. Central Animal Research Facility, Kasturba Medical College, Manipal Academy of Higher Education, Manipal, India.
9. Department of Animal Husbandry and Veterinary Sciences, Udupi, India.

ABSTRACT

Background and Aim: Antimicrobial resistance (AMR) is a growing global health threat with significant implications across human, animal, and environmental sectors. In veterinary settings, inappropriate antimicrobial use accelerates the emergence and dissemination of resistant pathogens through the food chain, direct contact, and environmental pathways. Despite national action plans, evidence on antimicrobial stewardship (AMS) at subdistrict levels remains limited, particularly in low- and middle-income countries. This study aimed to assess veterinarians' knowledge, attitudes, and practices (KAP) regarding AMS and to identify system level drivers influencing antibiotic prescribing in the Udupi district of coastal Karnataka, India.

Materials and Methods: A cross-sectional mixed-methods design was employed between April 2021 and March 2023. Quantitative data were collected using a structured KAP survey administered to all registered veterinarians in the district, while qualitative insights were obtained through in-depth semi-structured interviews. Descriptive statistical analysis was conducted for survey data, and thematic analysis was applied to qualitative data to explore contextual determinants of prescribing behavior.

Results: Of 43 eligible veterinarians, 27 participated (response rate: 62.7%). Mean scores for knowledge, attitude, and practice were 16.7, 47, and 9, respectively, indicating moderate knowledge and attitudes but suboptimal practices. High reliance on the highest priority critically important antibiotics, including enrofloxacin (77.8%) and ceftriaxone (66.7%), was observed for common conditions such as mastitis and enteritis. Although 59.3% reported access to microbiology laboratories, only 37.1% regularly utilized culture and sensitivity testing. Qualitative findings revealed that prescribing practices were shaped by interconnected systemic, economic, and socio-cultural factors, including diagnostic constraints, treatment costs, client expectations, and informal antibiotic access. A notable gap between awareness and implementation of AMS principles was identified.

Conclusion: This study highlights critical gaps in veterinary AMS at the district-level, characterized by overreliance on critical antibiotics, limited diagnostic utilization, and systemic barriers to evidence-based prescribing. Effective AMS implementation requires context-specific interventions, including mandatory training, improved diagnostic infrastructure, locally tailored prescribing guidelines, and multisectoral coordination under a One Health framework.

Corresponding Author: Chiranjay Mukhopadhyay

E-mail: chiranjay.m@manipal.edu

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Co-authors: NPM: ninupm@gmail.com, UB: unnikrishnan.b@manipal.edu, MDV: muralidhar.varma@manipal.edu,

RACR: r.ruiter@maastrichtuniversity.nl, VKE: vandana.ke@manipal.edu, GT: girish.thunga@manipal.edu, AK:

asha.kamath@manipal.edu, VLR: rvanilakshmi@outlook.com, JSS: jagnoor.sandhu@manipal.edu SS: shettyshankar63@gmail.com

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Keywords: antimicrobial resistance, antimicrobial stewardship, antibiotic prescribing, India, knowledge attitude practice, One Health, veterinary practice, zoonotic transmission.

INTRODUCTION

Antimicrobial use in the Indian veterinary sector is extensive and highly heterogeneous, with high levels of inappropriate antibiotic use in livestock in rural areas [1]. From a One Health perspective, antimicrobial resistance (AMR) originating in animals extends beyond farms, facilitating the transmission of resistant pathogens and genes to humans through direct contact, the food chain, and the environment [1]. Multiple factors drive antibiotic misuse in the veterinary sector, including low awareness among animal owners, unregulated over-the-counter access to antimicrobials, inadequate surveillance systems, limited laboratory infrastructure, and reliance on empirical therapy without diagnostic confirmation [2]. Evidence from South India highlights underutilization of culture and sensitivity testing, insufficient training in antimicrobial stewardship (AMS), weak regulatory enforcement, limited farmer education, and economic pressures influencing prescribing decisions [3, 4]. Similar challenges have been reported across other low- and middle-income countries (LMICs), such as Nigeria, Kenya, and Bangladesh, where poor awareness, limited diagnostics, veterinary workforce shortages, and cost barriers are common [5–10].

In veterinary practice, AMS encompasses coordinated strategies to optimize antimicrobial selection, dosing, duration, diagnostic use, infection prevention, and adherence to withdrawal periods to limit AMR and safeguard human, animal, and environmental health [11, 12]. India's National Action Plan on Antimicrobial Resistance (NAP-AMR) calls for subnational data on AMR awareness and antibiotic use among health care professionals, including veterinarians [13]. However, existing surveillance systems, such as the Indian Network for Fishery and Animal Antimicrobial Resistance (INFAAR), largely operate at national or higher administrative levels, limiting their relevance for subdistrict implementation [14].

Coastal Karnataka, particularly the Udupi district, represents a significant AMR hotspot. Studies have reported high resistance levels among livestock pathogens, including fluoroquinolone- and tetracycline-resistant *Escherichia coli* and *Klebsiella pneumoniae* [15]. Concurrently, high burdens of multidrug-resistant and carbapenem-resistant pathogens are documented in clinical settings and wastewater, indicating a convergence of clinical, veterinary, and environmental AMR risks [15–19]. Despite this, no studies have assessed knowledge, attitudes, and practices (KAP) related to AMS or system level barriers among veterinarians at the district or subdistrict level.

Despite increasing recognition of AMR as a critical One Health challenge, there is a substantial lack of granular, district-level evidence on veterinary AMS practices in India. Most existing studies have been conducted at national or state levels and have relied either on quantitative surveys or qualitative assessments independently, limiting the ability to capture the interaction between knowledge, attitudes, systemic constraints, and prescribing behavior. Furthermore, there is inadequate understanding of how contextual factors such as diagnostic accessibility, economic pressures, client expectations, and informal antibiotic access influence real-world prescribing decisions among veterinarians.

Importantly, while surveillance frameworks such as NAP-AMR and INFAAR emphasize multisectoral coordination, their implementation at subdistrict levels remains poorly characterized. The absence of localized antibiograms, district-level stewardship programs, and operational One Health integration creates a critical gap between policy and practice. In addition, evidence on the knowledge–practice gap among veterinarians, particularly in resource-constrained settings, remains limited, restricting the development of targeted, context-specific AMS interventions.

Grounded in the KAP framework and a One Health implementation perspective, this study aimed to address the existing evidence gap by conducting a comprehensive district-level assessment of veterinary AMS in the Udupi district of coastal Karnataka, India. Specifically, the objectives of the study were: (1) to quantify veterinarians' KAP related to AMS, and (2) to identify systemic, behavioral, and contextual drivers influencing antibiotic prescribing practices. By integrating quantitative and qualitative approaches, this study sought to generate actionable, context-specific evidence to inform the design and implementation of effective, district-level AMS interventions aligned with national priorities under NAP-AMR.

MATERIALS AND METHODS

Ethical considerations

Ethical approval was obtained from the Institutional Ethics Committee (IEC) of Kasturba Medical College and

Kasturba Hospital (IEC 624/2020). This study was registered with the Clinical Trial Registry of India (CTRI/2021/01/030448). Participants were informed that participation was voluntary, independent of their employer, would not affect their employment or evaluation, and that they could withdraw at any time without penalty, even after data collection. Written informed consent was obtained from all participants. Confidentiality was maintained through anonymization and secure data storage.

Study design, period, and location

This cross-sectional mixed-methods study was conducted in the Udupi district, Karnataka's western coastal region, between April 2021 and March 2023. A convergent mixed-methods design was employed, integrating quantitative and qualitative components to provide a comprehensive understanding of AMS among veterinarians. The quantitative component assessed veterinarians' KAP related to AMS, while the qualitative component explored system level and behavioral barriers influencing antimicrobial prescribing. The integration of both components enhanced the contextual interpretation and applicability of the findings [13, 20, 21].

According to the 2019 Livestock Census, the Udupi district has a substantial animal population, comprising over 250,000 cattle and more than one million poultry birds [22]. Despite this high livestock density, the availability of the veterinary workforce remains limited. In 2019, only 43 veterinarians were registered across government and private veterinary facilities, indicating a significant mismatch between service demand and workforce capacity.

Study population and sampling strategy

The study population included all registered veterinary doctors practicing in public and private veterinary facilities in the Udupi district who were willing to participate. Given the small, well-defined sampling frame ($n = 43$), a complete enumeration strategy was adopted to maximize representativeness and minimize selection bias.

To reduce non-response bias, multiple contact attempts, including phone calls, reminders, and follow up visits, were made. Data collection was scheduled at the convenience of the participants. Although a response rate of 90% or higher was targeted, 27 veterinarians (62.7%) completed the survey. The recruitment details and characteristics of the non-responders are presented in Figure 1.

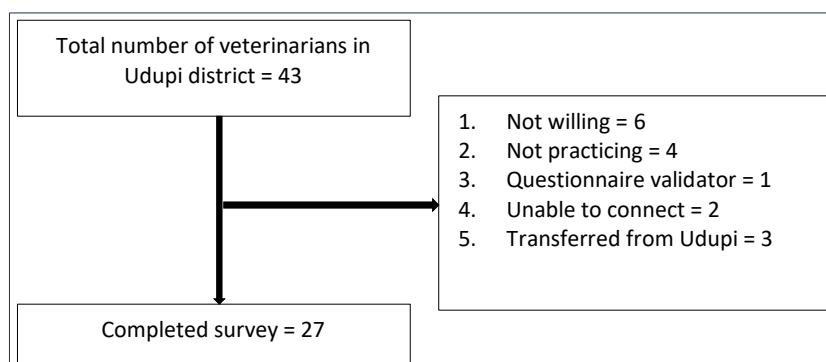


Figure 1. Recruitment details for the cross-sectional quantitative survey. Of the 43 veterinarians registered in the Udupi district, 33 met the inclusion and exclusion criteria. During the study period, three participants were transferred to another district, two could not be reached, and one was excluded because the individual served as a content validity expert for the study instrument, thereby minimizing confirmation bias or observer bias.

Inclusion and exclusion criteria

Eligible participants were veterinary doctors holding a minimum qualification of Bachelor of Veterinary Medicine and Animal Husbandry and actively practicing in the Udupi district during the study period. Interns, para-veterinary staff, unlicensed practitioners, and veterinarians not practicing in the district were excluded. Of the 43 veterinarians identified through the Department of Animal Husbandry registry, 27 met the inclusion criteria and consented to participate.

Questionnaire development and validation

The questionnaire was developed following a review of published KAP studies and informed by key international and national policy documents, including the World Health Organization Global Action Plan on Antimicrobial Resistance (2015), World Health Organization guidelines on medically important antimicrobials in food-producing animals (2017), the World Organization for Animal Health list of veterinary antimicrobials, and India's NAP-AMR [13, 23, 24].

Three subject experts assessed face validity. Content validity was evaluated by a five-member multidisciplinary expert panel using a 4-point ordinal scale [25]. Minor revisions improved clarity and incorporated AMS and One Health awareness items. Although formal psychometric reliability testing was not feasible due to the small sample size ($n = 43$), item clarity and internal consistency were reinforced through expert review and feedback with medical microbiology and infectious diseases experts.

The final questionnaire (Supplementary File A) assessed three domains:

- Knowledge: antibiotics, AMR mechanisms, and transmission pathways
- Attitude: perceptions related to AMR risk, stewardship, and regulation
- Practice: prescribing behavior, diagnostic utilization, and guideline adherence

Quantitative data collection

Data were collected using both online (Google Forms) and offline (paper-based) modes to minimize non-coverage bias. Identical questionnaires were used across modes to ensure comparability. Paper-based respondents completed forms privately to reduce social desirability bias. The questionnaire required 20–30 min to complete. To prevent missing data, online forms were configured with mandatory responses.

Qualitative sampling and interview procedures

Purposive sampling was used for the qualitative component of the study. Of the 18 survey respondents who consented to the interviews, 15 were selected to ensure diversity in experience, seniority, and practice setting. The primary researcher conducted semi-structured, face-to-face interviews in English. Thematic saturation was reached after 12 interviews, and three additional interviews were conducted for confirmation.

A validated interview guide, reviewed by experts from multiple disciplines, was used and piloted with two veterinarians (Supplementary File B). The interviews were conducted in English, and participants were allowed to use their local language to ensure clarity. Interviews lasted 30–60 min, were audio-recorded with consent, and were securely stored.

Qualitative data management and analysis

The interviews were transcribed verbatim and reviewed for accuracy. Data were analyzed inductively using manual coding. A codebook was iteratively developed, and a second coder independently reviewed the coding framework. Discrepancies were resolved by consensus. Thematic analysis followed Braun and Clarke's six-step framework [26].

Integration of quantitative and qualitative findings

Integration occurred during the interpretation stage. First, quantitative findings were analyzed, and qualitative themes were used to contextualize observed patterns, such as high AMR awareness alongside empirical prescribing. A data integration matrix was used to support triangulation (Table 6).

Operational definitions

The definitions of AMS, high priority critically important antibiotics (HPCIA), One Health awareness, and KAP scoring categories were based on the World Health Organization and modified Bloom's cut-off criteria [11, 12, 23, 24, 27, 28].

Data management and statistical analysis

Survey data were entered into Microsoft Excel and analyzed using Jamovi (Version 2.6). Analyses were limited to descriptive statistics because of the small sample size and skewed distributions. Inferential analysis was not performed.

RESULTS

Of the 43 veterinarians contacted, 27 participated, yielding a response rate of 62.7%. The participants were predominantly male (85.2%) and represented a broad age range. Most had over 10 years of professional experience (59.3%), practiced in rural settings (66.6%), and were employed in government veterinary hospitals (88.9%), reflecting the district's public sector dominated veterinary infrastructure. Nearly half of the study participants managed primarily large-animal caseloads, while one-third reported mixed practice. Notably, 81.5% of the participants had not received any formal training on antimicrobial prescribing in the preceding year, providing an important context for the observed knowledge–practice gaps. Demographic and professional characteristics are summarized in Table 1.

Table 1: Demographic and professional profiles of the veterinary doctors.

Demographic variables	Frequency	Percentage
Gender		
Male	23	85.2
Female	4	14.8
Age		
20–30 years	7	25.9
31–40 years	5	18.5
41–50 years	7	25.9
>50 years	8	29.6
Hospital		
Government hospital	24	88.9
Private hospital	1	3.7
Private clinic	2	7.4
Professional qualification		
Graduate	16	59.3
Postgraduate	11	40.7
Years of professional experience		
<5 years	6	22.2
5–10 years	5	18.5
>10 years	16	59.3
Types of animals treated		
Large animals	15	55.6
Small animals	4	14.8
Mixed practice	8	29.6
Rural–urban distribution		
Urban	9	33.3
Rural	18	66.6
Training on antimicrobial prescribing (past year)		
Yes	5	18.5
No	22	81.5

KAP scores

Mean (\pm standard deviation) scores for knowledge, attitude, and practice were 16.7 ± 3.57 , 47 ± 3.67 , and 9 ± 2.01 , respectively (Table 2). Veterinarians with more than 10 years of experience demonstrated higher knowledge and more favorable attitudes; however, these did not consistently translate into appropriate prescribing practices. In contrast, early-career veterinarians (<5 years) had lower knowledge scores but reported greater guideline adherence. Veterinarians who received recent training demonstrated improved knowledge and attitudes; however, practice scores remained suboptimal, suggesting that training alone may not be sufficient to overcome contextual and systemic barriers.

Table 2: Knowledge, attitudes, and practices score distribution among veterinary doctors.

Score category	Knowledge (%)	Attitude (%)	Practice (%)
Poor (<50%)	11.1	0	37.03
Moderate (50%–75%)	51.8	18.5	59.25
Good (>75%)	37.03	81.48	3.7

Knowledge regarding antimicrobial use and AMR

Most respondents correctly identified key drivers of AMR, including bacterial mutation (88.9%), rapid microbial adaptation (88.9%), and horizontal gene transfer (77.8%) (Table 3). Overprescription, inappropriate use of broad-spectrum antibiotics, and incorrect dosing were widely recognized as contributing factors. Two-thirds of respondents acknowledged animal-to-human transmission of resistant bacteria, and 62.9% recognized risks from contaminated meat. All respondents agreed that AMR is a serious problem.

Despite this high conceptual awareness, important misconceptions persisted. Nearly half of the respondents endorsed the use of prophylactic antibiotics in mild cases or held incorrect beliefs about the complete eradication of susceptible bacteria. Only 62.9% accurately described AMS, indicating moderate stewardship literacy. Overall, knowledge was moderate to good, but gaps remained regarding prophylaxis, long-term antibiotic effectiveness, and host–pathogen resistance dynamics (Table 4).

Table 3. Item-wise knowledge responses toward antibiotic use and AMR among veterinary doctors in the Udupi district (n = 27).

No.	Knowledge items	Correct	Incorrect
1	What do you think is the difference between an antibiotic and an antimicrobial?	25 (92.2%)	2 (7.4%)
2	Antibiotic treatment can remove all sensitive bacteria at the site of infection.	15 (55.6%)	12 (44.4%)
3	The antibiotics we use today can be effective in the future.	13 (48.1%)	14 (51.9%)
4	It is appropriate to use antibiotics as a preventive tool in animals when there is no clinically diagnosed disease.	21 (77.8%)	6 (22.2%)
5	Using antibiotics as a preventive tool in animals is appropriate when there is no chance of high-risk spread of an infectious disease in animals.	20 (74.1%)	7 (25.9%)
6	It is appropriate to use antibiotics as a preventive tool in animals with mild disease.	15 (55.6%)	12 (44.4%)
7	A medically important antibiotic can be used to treat an infection in animals without a clinical diagnosis.	20 (74.1%)	7 (25.9%)
8	Antibiotic resistance develops when animals develop resistance to antibiotics.	18 (66.7%)	9 (33.3%)
9	Antibiotic resistance develops when bacteria develop antibiotic resistance.	23 (85.2%)	4 (14.8%)
10	Antibiotic resistance develops when antibiotics stop adapting to bacteria changes.	15 (55.6%)	12 (44.4%)
11	Transmission of resistant bacteria from animals to humans.	18 (66.7%)	9 (33.3%)
12	An antibiotic-resistant infection in a cow poses a threat to the rest of the herd.	20 (74.4%)	7 (25.9%)
13	Prescribing antibiotics used in human medicine for animals would not contribute to antimicrobial resistance.	14 (51.9%)	13 (48.1%)
14	Bacterial mutations are a driver for AMR.	24 (88.9%)	3 (11.1%)
15	Rapid bacterial adaptation to changing conditions is a driver of AMR.	24 (88.9%)	3 (11.1%)
16	Incorporation of mobile genetic elements from resistant bacteria into a pathogen that causes infection in humans is a driver of AMR.	21 (77.8%)	6 (22.2%)
17	The over-the-counter availability of antibiotics in pharmacies does not contribute to the development of antibiotic resistance.	19 (70.3%)	8 (29.7%)
18	Overprescription and overconsumption of antibiotics are AMR drivers.	21 (77.8%)	6 (22.2%)
19	Using broad-spectrum antibiotics (antibiotics that are effective against various organisms) is a driver of AMR.	21 (77.8%)	6 (22.2%)
20	Inappropriate dose prescription is a driver of AMR.	21 (77.8%)	6 (22.2%)
21	Inappropriate course duration is a driver for AMR.	19 (70.3%)	8 (29.7%)
22	Consumption of meat contaminated with resistant bacteria is a driver of AMR.	17 (62.9%)	10 (37.03%)
23	Using broad-spectrum antibiotics is a driver for AMR.	21 (77.8%)	6 (22.2%)
24	Exposure of farm animals to antibiotics.	17 (62.9%)	10 (37.03%)

AMR = Antimicrobial resistance.

Table 4. Misconceptions related to antimicrobial resistance and antibiotic use.

No.	Knowledge items	Incorrect	Misconception types	Implications for AMS training
1	The antibiotics we use today can be effective in the future.	14 (51.9%)	Long-term antibiotic effectiveness	Emphasis on the need to conserve antimicrobials for future effectiveness
2	Antibiotic treatment can remove all sensitive bacteria at the site of infection.	12 (44.4%)	Selective pressure in AMR	Training needs for antimicrobial resistance mechanisms
3	It is appropriate to use antibiotics as a preventive tool in animals with mild disease.	12 (44.4%)	Indication for antibiotic treatment is inappropriate	Strengthening training on guidelines and treatment protocol-based prescribing
4	Antibiotic resistance develops when antibiotics stop adapting to bacteria changes.	12 (44.4%)	Resistance mechanism	Clarification of bacterial adaptation and resistance mechanisms
5	Prescribing antibiotics used in human medicine for animals would not contribute to antimicrobial resistance.	13 (48.1%)	One Health link	Include One Health linkage in the curriculum as a top priority

AMR = Antimicrobial resistance, AMS = Antimicrobial stewardship.

Knowledge regarding One Health

One Health awareness was limited and fragmented. Only 50.9% were familiar with the One Health approach. While 67% recognized animal-to-human transmission, understanding of food chain and environmental pathways was poor, with 37% providing incorrect responses. These findings suggest that awareness of One Health is largely confined to zoonotic transmission, with limited appreciation for broader ecological pathways. The role of veterinarians in AMR from a One Health perspective is provided in Figure 2.

Antibiotic prescribing practices

All respondents prescribed antibiotics in the preceding six months. Mastitis, skin wounds, and enteritis were the most frequent indications (Figure 3). The most commonly prescribed agents were HPClAs, including enrofloxacin (77.8%) and ceftriaxone (66.7%), followed by oxytetracycline and gentamicin (40.7% each) (Figure 4). The routine use of restricted antibiotics for common conditions highlights significant gaps in AMS.

Client education on AMR was inconsistent: only 3.7% of cases were always counseled by animal handlers, while over 70% reported rare discussions of multidrug resistance.

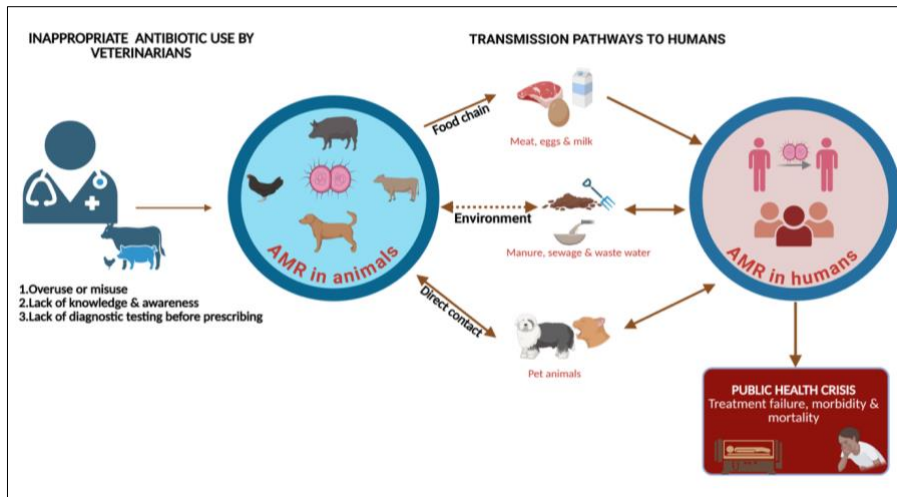


Figure 2: Schematic representation of the pathways through which inappropriate antibiotic use in veterinary practice contributes to AMR in humans through the food chain, environmental contamination, and direct contact, ultimately leading to a public health crisis.

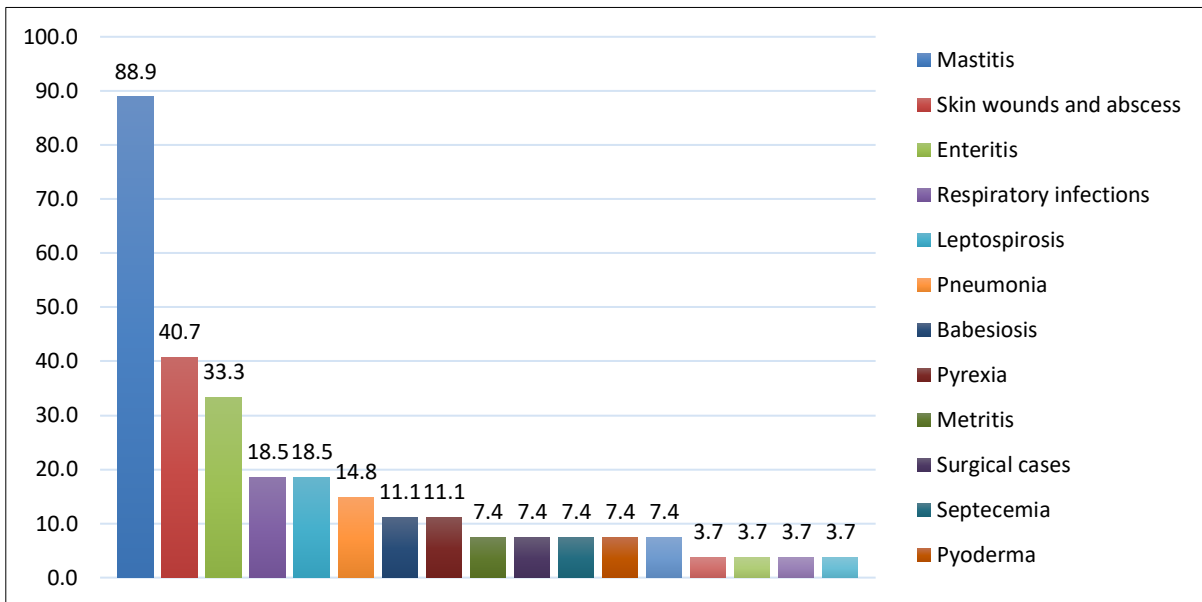


Figure 3: Distribution of the most common infections for which veterinarians in Udupi prescribe antibiotics. Mastitis was the most frequently reported condition (88.9%), followed by skin wounds and abscesses (40.7%), enteritis (33.3%), and respiratory infections and leptospirosis (18.5%).

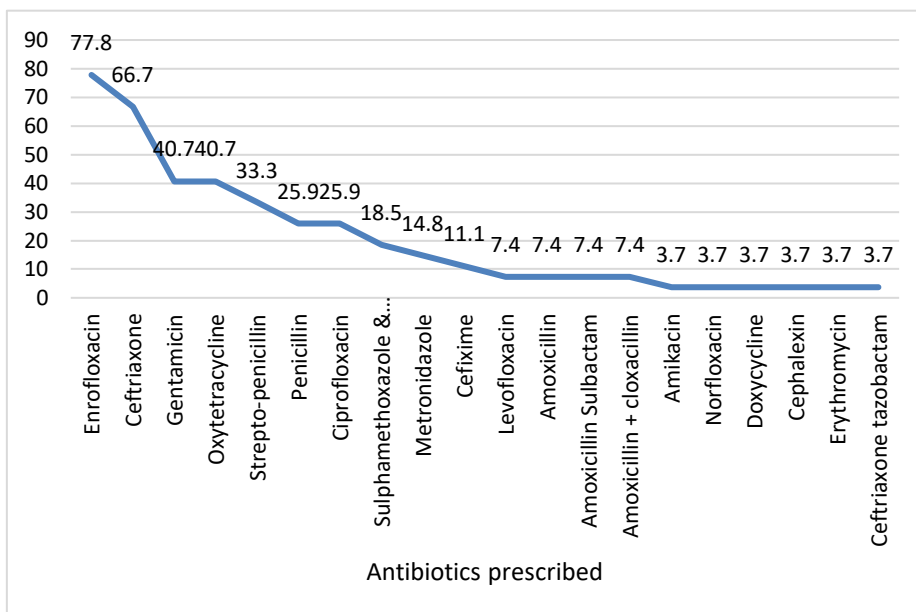


Figure 4: Frequency of antibiotics most commonly prescribed by veterinary practitioners in Udupi. Enrofloxacin was the most frequently prescribed agent (77.8%), followed by ceftriaxone (66.7%). Oxytetracycline (40.7%) and gentamicin (40.7%) were the most commonly used highly important antibiotics, followed by strepto-penicillin (33.3%) and penicillin (25.9%). Lower prescription frequencies were recorded for sulfamethoxazole (18.5%) and metronidazole (14.8%).

Diagnostic access and use

Access to microbiology laboratories was limited, with 40.7% reporting no access. Empirical prescribing predominated, and routine use of culture and sensitivity testing was low (43.7%) even among those with access, indicating that availability alone does not ensure evidence-based practice.

Guidelines, infection prevention and control, and training

Guideline use was inconsistent, with only 11.1% always using them. Most relied on outbreak advisories rather than prescribing guidelines. Infection prevention and control programs were present in only 14.8% of facilities, and 74.1% did not receive regular AMR surveillance updates. The majority (81.5%) had not received recent AMS training.

Attitudes and systemic barriers

Despite universal recognition of the severity of AMR, nearly half were willing to use reserve antibiotics, and more than half found broad-spectrum prescribing easier than diagnostic confirmation. These contradictions reflect systemic constraints influencing prescribing behavior. Table 5 demonstrates the veterinarians' attitude toward AMS and AMR.

Table 5: Attitude towards AMR and AMS.

No.	Attitude items	Highly agree, n (%)	Agree, n (%)	Neutral, n (%)	Disagree, n (%)	Highly disagree, n (%)
1	Antibiotic resistance is a serious public health concern.	21 (77.8%)	6 (22.2%)	0 (0%)	0 (0%)	0 (0%)
2	Antibiotic resistance is a serious health problem in India.	20 (74.1%)	7 (25.9%)	0 (0%)	0 (0%)	0 (0%)
3	Antibiotic resistance is an issue that can be solved by developing new antibiotics.	2 (7.4%)	1 (3.7%)	5 (18.5%)	15 (55.6%)	4 (14.8%)
4	Antibiotic resistance has a negative impact on animal health (growth and transmission of resistant bacteria among animals, leading to therapy failure).	7 (25.9%)	15 (55.6%)	2 (7.4%)	3 (11.1%)	0 (0%)
5	Do you agree that antibiotics are being overused in the animal sector?	3 (11.1%)	17 (63.0%)	3 (11.1%)	3 (11.1%)	1 (3.7%)
6	Restricting the use of antibiotics for growth promotion in food-producing animals is an important step in reducing antibiotic resistance in humans.	11 (40.7%)	10 (37.0%)	3 (11.1%)	3 (11.1%)	0 (0%)
7	The use of antibiotics in food-producing animals can impact human health.	13 (48.1%)	10 (37.0%)	2 (7.4%)	2 (7.4%)	0 (0%)
8	An individual antibiotic prescribing behavior contributes to the development of antibiotic resistance within a given region.	7 (25.9%)	12 (44.4%)	5 (18.5%)	3 (11.1%)	0 (0%)
9	Antibiotic guidelines are more of an obstacle to clinical care.	1 (3.7%)	6 (22.2%)	7 (25.9%)	11 (40.7%)	2 (7.4%)
10	I would prefer prescribing an antibiotic of the animal owner's choice rather than finding the infection's cause.	0 (0%)	0 (0%)	0 (0%)	9 (33.3%)	18 (66.7%)
11	I would prefer a restricted/reserved antibiotic over an alternative.	5 (18.5%)	8 (29.6%)	7 (25.9%)	6 (22.2%)	1 (3.7%)
12	Preferring a broad-spectrum antibiotic is easier than definitive therapy, which might require culture and sensitivity.	3 (11.1%)	11 (40.7%)	5 (18.5%)	6 (22.2%)	2 (7.4%)

AMR = Antimicrobial resistance, AMS = Antimicrobial stewardship.

Qualitative and integrated findings

Qualitative analysis identified structural (laboratory gaps, workforce shortages, and costs), interpersonal (client expectations and poor adherence), and socioeconomic (over-the-counter antibiotic access, unqualified practitioners, and poverty) drivers of misuse (Table 6). The integrated findings (Table 7) confirmed that stewardship failures are primarily driven by systemic and economic constraints rather than a lack of awareness, underscoring the need for district-level, context-specific AMS interventions that extend beyond education alone. A thematic map of the various systemic, behavioral, and contextual factors influencing antibiotic prescription practice is provided (Figure 5).

Table 6: Themes and verbatim supporting data from the qualitative study.

Theme	Category	Supporting verbatim	Interpretation
Structural or health system level issues	Lack of laboratory facilities	Vet 7: "We don't have ready facilities for the labs, so we will be talking to our polyclinic doctors and decide on treatment." Vet 8: "Usually, what happens in the village area is that it is very difficult to know the resistance because we need to take the samples to the lab, which is far away, and they must be processed there. Lack of proper facilities in rural areas. It really becomes difficult for us to treat; this is the fact." Vet 11: "And again comes the question of affordability and	Diagnostic accessibility, cost, and report delay influence empirical therapy.

Theme	Category	Supporting verbatim	Interpretation
Structural or health system level issues	Administrative workload	antibiotic sensitivity testing. Samples are usually sent to the laboratory or to Manipal for antibiotic sensitivity testing. If the owner is okay with that, we used to send it, but it happens very rarely."Vet 1: "Mastitis requires immediate treatment; culture sensitivity will take a minimum of 48 hours to achieve. Once again, when we run the experiment, it is difficult."Vet 2: "For a really simple blood checkup, we don't have a laboratory. We rely on private laboratories; the tests cost 500–600 Rs. We must pay from our own pockets; I have personally done this. It will take at least 48 h. By the time the result comes, the animal will die."Vet 7: "And we don't have that much time either. It will require at least one day for that. By the time we get the result, the condition of the animal will be worse. We don't have ready facilities for the labs, so we will be talking to our polyclinic doctors and decide on the treatment."Vet 8: "A poor man from Neralakatte or Kollureu cannot bring the animal here; I must go there. I need to obtain a blood sample, which must be sent to either Mangalore or Udupi, 60–70 km away. How costly and burdensome it is, despite a cow costing around Rs 12,000 to 15,000 or 20,000. He must spend Rs 2,000–3,000 for the clinical examination."Vet 10: "The animal is already very sick, and if I ask for antibiotic sensitivity testing results, they will need a minimum of 48 hours. How can I manage that 48 hours? This is the main problem."	Workload affects field visits and continuity of antibiotic therapy.
Structural or health system level issues	Workforce shortages	Vet 8: "I am telling you the practical problem I am facing. Doctors handle a tremendous amount of work, often attending multiple clinics and attending training sessions. Consequently, doctors may not receive their animal owners' phone calls at all. This is a field problem, and the doctor works at three or four institutions at a time. The man in Bippalkatte wants a doctor, but doctors are far away. So, what does he do? He approaches a local man, who gives him an injection and then leaves, and he charges a lower fee as well."Vet 9: "The main thing is that there is no manpower in this department. Only doctors are running the hospital."	Lack of manpower affects treatment and management of cases in facilities.
Structural or health system level issues	Lack of policy and guidelines	Vet 3: "I told you earlier that based on our experience, we are using drugs not based on a policy or guideline. Do we know what drugs work based on our experience? We should look into these things, not just one stakeholder, and the government should form a policy for that."Vet 4: "I think penicillin is recommended for certain diseases like leptospirosis. Okay. We do not have that kind of guidelines or policies."Vet 6: "If local resistance pattern is available to us, it will be helpful; at least in Taluks or every district, they should conduct a culture test and assess sensitivity and antibiotic resistance, and they should update every three months or six months. At least they can say this antibiotic is getting resistance. They can recommend which drug to use. We should have these policies as we see among human health. We should have guidelines. Do not use any antibiotics. Please restrict the use of antibiotics. In the same way, we should get the updates."Vet 7: "We do not have a proper chart kind of thing where we can paste and all. We will be having knowledge; we don't have specific guidance on that. It's not like we don't have knowledge, but we are not having updated knowledge."Vet 8: "There is no such thing as that in veterinary. So far, I have not received it. Recently, we received a letter about a disease called lumpy skin disease, so for treatment of this some Ayurvedic churna and some medicines were prescribed, that is the only case where a letter was received. No one will have seen anything else; I have never seen."Vet 10: "That is the main problem. The main drawback in our department is that we do not have that kind of pattern in our institutions. Definitely, it is required. Last month, you might have observed lumpy skin disease. In my 15 years of experience, that is the one guideline that was released on how to treat these cases. Those kinds of teams are required at the higher level, and they should also percolate to the lower level officers. Otherwise, it will be difficult."Vet 11: "No, no, no such guidelines for us, but we usually treat based on our experience and with our previous knowledge. Yes, yes."	Lack of local antibiotic policies leads to reliance on experience and prior knowledge.
Structural or health system level issues	Implementation challenges	Vet 2: "Guidelines will be there, but difficult to implement, practical difficulties, lack of manpower, workload, and if we have sufficient time and sufficient equipment, we can solve."Vet 3: "There is no need to change, but implementation is important. Veterinarians know what should be prescribed, but practicing what they know is very important."	Implementation barriers limit effective AMS.
Structural or health system level issues	High cost of antibiotics	Vet 1: "All antibiotics are expensive; farmers cannot afford them. Even if they want, they might pay for one shot, and once the animal recovers, that is all."Vet 5: "The second thing is that in veterinary practice, all antibiotics are very costly;	Economic constraints determine antibiotic prescription decisions.

Theme	Category	Supporting verbatim	Interpretation
Practice level or interpersonal factors	Lack of adherence to therapy by animal owners	we cannot afford them, and they should be patient-oriented."Vet 6: "It is a financial issue, they should give the medicine. If the medicine is available in the government hospital, we will give it for free, no problem."Vet 7: "That's what happens when we choose a higher-end antibiotic, the prices will be higher, and it will be costly for an animal."	Poor adherence limits effectiveness and increases AMR risk.
Practice level or interpersonal factors	Animal owners cannot afford antibiotics	Vet 11: "If I prescribe for five days, they will buy for one or two days. If the condition gets better by one or two doses, they will skip a dose of that antibiotic, and they do not follow up much. But most of the time, they skip doses. That is the main challenge we are facing, because no complete antibiotic course is happening in veterinary practice."Vet 6: "So, this is mainly regarding mastitis. When we go for treatment, the enrofloxacin schedule should be at least three days, but it can be five days. We will visit the owner and administer the treatment, and the next day, the animal will be okay. We will tell them we should give it for three days, but 50% of the time they will not call. They think that their animal is alright. Furthermore, why should we again give you the antibiotics?"	Affordability determines antibiotic choice.
Practice level or interpersonal factors	Lack of awareness among animal owners	Vet 8: "The farmer is not bothered about handling these antibiotics; he is not aware of it. The farmer is not bothered because he does not know. He goes to the man who is easily accessible to him, that is the only problem with veterinarians."Vet 9: "Laymen do not know anything. They want just the results, but we have to teach them. So, the doctor has to do that."Vet 10: "Due to a lack of information from the owner, at the field level farmers are also playing a role in antibiotic resistance."	Farmer awareness is critical for AMS.
Practice level or interpersonal factors	Animal owners require immediate results	Vet 1: "Two things will happen: they want immediate results, and patients, doctors, and owners also need immediate results. This also creates many problems. That is one of the major things we lack in the field, and the farmers are not cooperative."Vet 9: "As for the animal owners, the animal should recover early. However, early recovery is not always beneficial and can also be unsafe. Nowadays, people are very eager, and their schedules are often hectic. They want the results as soon as possible. They will come today, and the animals will be alright tomorrow. Their expectations are very high."Vet 8: "This is a problem. Today, I am treating a cow here. The next day, if it doesn't subside, he will never go to the doctor again like human beings. He will go to another man. Today, I will start with amoxicillin, and the next day he will start with cefotaxime, and that's a problem."Vet 10: "Now if I am unable to make that animal normal within 24 hours, what the party will do? He will call another doctor. If I use amoxicillin today and the other doctor gives enrofloxacin, he will call another doctor and another antibiotic will be used after three days. So, this is the problem we are facing."	Pressure for rapid recovery promotes empirical and escalated antibiotic use.
Practice level or interpersonal factors	Noncompliance with the withdrawal period	Vet 1: "When it is mastitis, there is a need for seven days of withdrawal. If you're not following the seven-day withdrawal period and selling the milk, we will get an antibiotic through milk if it is not properly sterilized or boiled."Vet 3: "And one more thing is the withdrawal period, which is very problematic. We are telling them that this is the withdrawal period for such drugs, but nobody is following it. That will indirectly result in human resistance, with nobody following the milk withdrawal period. This is the biggest issue."Vet 6: "This withdrawal period is also an issue with antimicrobial resistance. We will tell them to follow the withdrawal period for seven or five days, whatever the antibiotic period is, but we do not know how far it is happening practically."	Weak compliance increases AMR and food safety risks.
Socioeconomic and community factors	Easy availability of over-the-counter antibiotics	Vet 3: "Even the farmers or the owner get medicine from the counter without a prescription. There, we must control."Vet 5: "Sometimes they also get it over-the-counter without a prescription."Vet 6: "They will be calling some other person, or they will be going directly to the medical shop. They will ask about some symptoms, and the pharmacist will prescribe medicine based on that. Sometimes, over the phone only, some people will just inform the pharmacists about signs of the animal disease, and the pharmacists will give the medicine by themselves. This is also an issue, irrational use."	OTC access facilitates inappropriate antibiotic use.
Socioeconomic and community factors	Quackery and malpractical practices in the animal sector	Vet 2: "Resistance means quackery will be there, homeopathy and quacks. They prescribe antibiotics more than us. Usually, I avoid them, but they give antibiotics despite not knowing what to write or the dosage. Most people will give antibiotics such as B complex vitamins."Vet 3: "In our field, one of the most serious issues is the random use of antibiotics by quacks; they are using random antibiotics. Many dairy sectors are using all kinds of antibiotics. Without knowing the pharmacokinetics, they are using drugs. That is the main culprit."	Informal providers contribute to irrational antibiotic use.
Socioeconomic and community factors	Inappropriate antibiotic prescription	Vet 3: "If three doctors are working in one place, they are using different drugs. That is a place where we will get resistance."Vet 4: "I have heard in some cases the unnecessary use of antibiotics in poultry and cows. It might play a role, see,	Non-uniform prescribing increases AMR risk.

Theme	Category	Supporting verbatim	Interpretation
Socioeconomic and community factors	Poverty	unnecessary prescription of antibiotics that we can avoid."Vet 9: "They think that all the animal owners should come to them. When they think that they must use higher-generation antibiotics to get the animals cured quickly, some doctors will do that, but it is not good and not advisable." Vet 2: "Some animal owners are ready to treat the animal, but they do not have money."Vet 3: "If you are treating mastitis, if I insist that the farmer withdraw the milk, then we have to compensate for his loss in terms of subsidy. Otherwise, he will not do it. That is important."Vet 6: "Poverty is also a reason. Because if I say do not give this animal milk for seven days, then the animal is giving 20 liters per day for seven days, which equals 140 liters. What should he do? He must pour it out. Who bears the expenses? The animal has to eat, he has to give the feed, and he has to manage for seven days, so who will bear the expenses? That is also an issue we cannot deny."	Economic constraints shape antibiotic use and compliance.
Recommendations or future directions	Need for training of doctors	Vet 7: "We have to give proper training to doctors; they need to be updated. Senior doctors can take inputs, discuss with government sectors, and form a team, make circulars and curriculum."Vet 8: "We need information from a veterinary microbiologist. Studies on organisms prevalent in specific areas and their patterns of antibiotic resistance are essential to guide effective treatments."	Training is essential for effective AMS.
Recommendations or future directions	Need for farmer education	Vet 2: "Here we have to guide what is the withdrawal period, why there is a need for three or five days of treatment, and why they should not just follow random treatment and purchase medicine."Vet 3: "More than treating animals, we have to treat the owners. We need to convince them rather than only treat."Vet 6: "Actually, everyone wants training to understand this. A layperson or an animal owner should also understand that treatment will last for 5–7 days. So, the women they are hiring, Accredited Social Health Activists, can be used for conveying these types of issues; they go door to door, and this can be shared through pamphlets. This can keep at least literate persons informed about antibiotic issues."	Farmer education is critical for stewardship.
Recommendations or future directions	Collective work	Vet 3: "It is a collective work from all the people who are involved in this. Not just veterinarians, farmers, or medical personnel are responsible. They all should sit together. That is the concept of One Health."Vet 6: "Antibiotic resistance is everybody's mistake; we cannot deny it by saying I do not play any role in it. All stakeholders are responsible for this; therefore, my opinion is the same. Everybody plays a role in antibiotic resistance, and we should minimize the use of antibiotics."	Multisectoral coordination is essential for AMS.

Table 7: Data integration matrix.

Quantitative findings	Verbatim from the qualitative study	Interpretation or integration	Recommended actions
37.1% of veterinarians could not describe AMS. 81.5% did not receive training.	"We must provide proper training to doctors; they need to be updated. Senior doctors can take inputs, discuss with government sectors, and form a team, make circulars and curriculum."	Quantitative data indicate a knowledge gap, and qualitative data confirm a lack of training.	Accredited continuous medical education on AMS should be mandatory for district-level license renewal and certification.
22.2% of veterinarians were unaware of medically important antibiotics and their proper usage in the animal sector.	"No, no, no, no such guidelines for us, but we usually treat based on our experience and previous knowledge. Yes, yes."	There is a knowledge gap, and there are no guidelines or updates to support practice.	Develop and mandate accessible national guidelines for antibiotics based on the World Organization for Animal Health and World Health Organization One Health principles.
44.7% of veterinarians said it is easier to use broad-spectrum antibiotics.	"For a simple blood checkup, we don't have a laboratory. We rely on private laboratories; the tests cost 500–600 Rs. We must pay from our own pockets; I have personally done this. It will take at least 48 h. By the time the result comes, the animal will die."	Aligns with social drivers for antibiotic misuse in rural areas, including lack of access or infrastructure and affordability barriers.	Strengthen rural laboratory infrastructure at the district-level and veterinary polyclinics. Provide subsidized or free culture and sensitivity testing. Integrate antibiotic sensitivity testing for the animal sector with current laboratory infrastructure in the human sector.
40.7% did not have access to a microbiology laboratory.	"Usually, what happens in the village area is that it is very difficult to know the resistance because we need to take the samples to the lab far away, and they have to be processed there. Lack of proper facilities in rural areas. It really becomes difficult for us to treat, this is the fact."	Inadequate laboratory access in rural areas is confirmed by both data sources.	Establish focal collection points for samples from multiple veterinary dispensaries. Integrate diagnostic services with the human sector, such as primary health centers, community health centers, or district hospitals. Train rural health workers in the collection and transport of animal samples.
62.9% did not recommend culture for definitive therapy.	"A poor man from Neralakatte or Kollureu cannot bring the animal here; I must go there. I need to get a blood sample, which must be sent to Mangalore or Udupi, 60–70 km away. How costly and burdensome it is, despite a cow costing around 12,000 to	Shows why veterinarians resort to empirical use of antibiotics and highlights systemic gaps.	Establish focal collection points for samples from multiple veterinary dispensaries. Strengthen rural laboratory infrastructure at district-level hospitals and veterinary polyclinics.

Quantitative findings	Verbatim from the qualitative study	Interpretation or integration	Recommended actions
56.2% did not recommend culture even with access to a culture facility.	15,000 or 20,000. He has to spend 2,000–3,000 for the clinical examination.” “And again, it comes to the question of affordability and antibiotic sensitivity testing. Samples are usually sent to the laboratory or, occasionally, to Manipal for antibiotic sensitivity testing. If the owner is okay with that, we used to send it, but it happens very rarely.”	Aligns with the economic and social aspects of AMR.	Establish a tiered laboratory network in which sample collection is done in rural clinics and antibiotic sensitivity testing is performed centrally at the district-level or polyclinic to reduce patient travel costs. Include antibiotic sensitivity testing under a national health scheme or ensure free testing services for animal owners.
44.4% did not use or refer to guidelines for antibiotic therapy.	“No, no, no, no such guidelines for us, but we usually treat them based on our experience and what we know from our previous knowledge. Yes, yes.”	Indicates lack of system level upgradation.	Develop and disseminate national veterinary antibiotic usage guidelines, as in the human sector.
62.9% of veterinarians did not have an infection prevention and control program, and 74.9% did not receive periodic updates.	“Guidelines will be there, but difficult to implement, practical difficulties, lack of manpower, workload, and if we have sufficient time and equipment, we can solve.”“We need information from a veterinary microbiologist. Studies on organisms prevalent in specific areas and their patterns of antibiotic resistance are essential to guide effective treatments.”	Aligns with barriers at the health system level and lack of structural support and training in the veterinary sector.	Develop infection prevention and control guidelines for the veterinary sector and programs at the national level, including NAP-AMR. Form a committee under the leadership of the Deputy Director of the Animal Husbandry Division to develop a local antibiogram and guidelines. Update these guidelines every 6 months. Distribute printed general infection prevention and control guidelines and local AMR patterns to all veterinary facilities. Conduct biannual monitoring of antimicrobial usage in veterinary facilities and prescription audits to ensure adherence. Provide positive reinforcement through accreditation or upgradation for the best-performing facilities in infection control.
High prescription of antibiotics for HPCIA and highly important antibiotics.	“If, within two days, there is no result, the patient will change the doctor. That is the biggest issue, and it is very difficult to convince farmers at that level.”	Brings out the financial and social aspects of antibiotic misuse.	Conduct awareness campaigns at the local level to raise awareness among animal handlers. Mobilize community health workers, such as Accredited Social Health Activists, to educate farmers regarding AMR.

HPCIA = High priority critically important antibiotics, AMR = Antimicrobial resistance, AMS = Antimicrobial stewardship, NAP-AMR = National Action Plan on Antimicrobial Resistance.

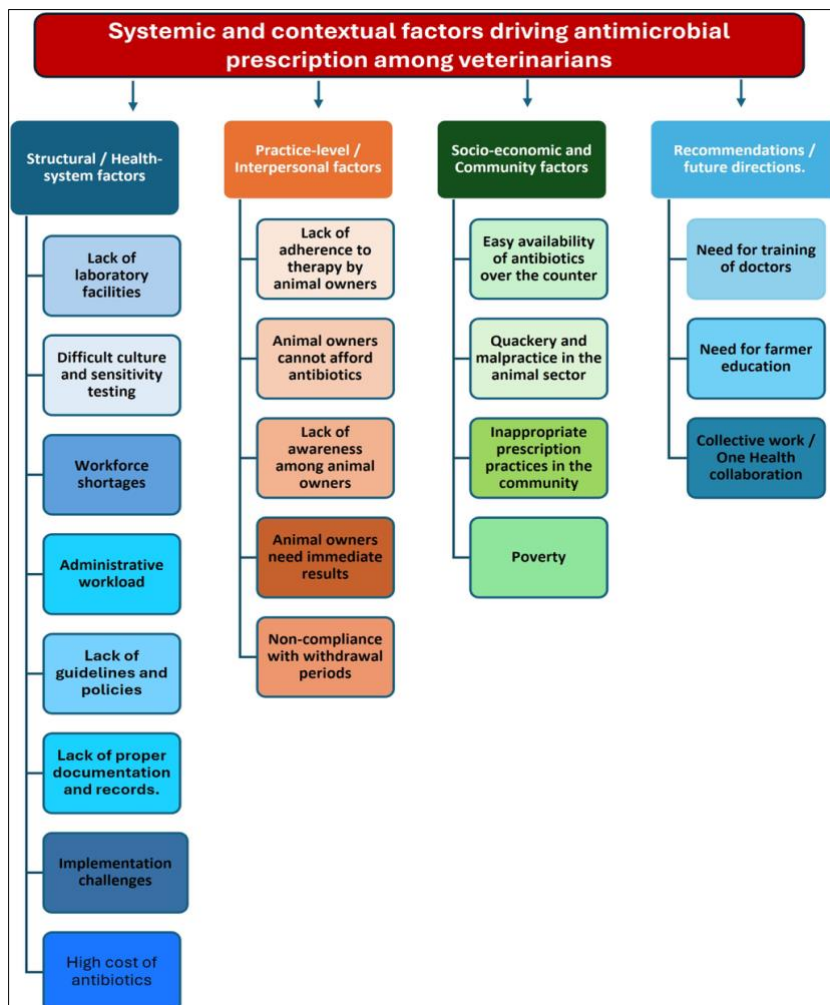


Figure 5. Thematic map showing the systemic, behavioral, and contextual factors influencing antibiotic prescribing practices among veterinarians in Udupi district, Karnataka.

DISCUSSION

Implications for NAP-AMR and district-level AMS

This study has substantial implications for India's NAP-AMR and its updated version, as it addresses a critical evidence gap at the subdistrict level through a mixed-methods assessment of AMS among veterinarians in Karnataka. Existing evidence on AMS in India is largely derived from national or state-level assessments, with no prior studies conducting a complete enumeration of veterinarians within a single district. By generating district-level, context-specific data, this study directly responds to the need for granular, locally actionable evidence to support the effective implementation of AMR containment strategies.

A key novelty of this study lies in its integration of quantitative KAP assessment with qualitative exploration of the systemic and behavioral drivers of antibiotic use. Unlike many studies from LMICs that rely exclusively on surveys or interviews, this study employs methodological triangulation within a KAP framework to reveal a pronounced knowledge–practice paradox. Veterinarians demonstrated awareness of AMR risks yet continued to rely heavily on HPClAs and empirical prescribing.

Although national standard treatment approaches permit initial empirical therapy for common conditions such as mastitis and enteritis, they emphasize diagnostic-guided treatment. In contrast, the routine use of broad-spectrum antibiotics without prior or follow up diagnostic confirmation, as observed in this study, reflects misalignment with AMS-oriented prescribing principles.

Notably, even when laboratory services were accessible, the costs and delays associated with culture and sensitivity testing discouraged diagnostic use. This paradox highlights that stewardship failures are driven not only by lack of awareness or infrastructure but also by economic constraints, expectations of rapid clinical response, challenges in follow up care, limited diagnostic support, and client pressure. These findings underscore the need for greater emphasis on applied stewardship, diagnostic interpretation, communication skills, and economic decision-making to prepare veterinarians for real-world clinical contexts.

Role of para-veterinarians and workforce dynamics

Qualitative findings highlight the significant role of para-veterinary personnel and unqualified practitioners in inappropriate antibiotic use. While these actors often fill critical service gaps in rural areas, insufficient regulation enables indiscriminate antimicrobial use, undermining formal veterinary health care systems. Therefore, addressing AMR in LMICs requires regulated integration, structured training, and supervision of para-veterinary cadres rather than their exclusion from AMS frameworks.

Although female veterinarians constituted a smaller proportion of the study population and no gender-specific prescribing patterns were identified, future research should examine whether gender-related factors influence stewardship practices.

Policy context and state-level comparisons

Several Indian states, including Kerala, Tamil Nadu, and Maharashtra, have implemented AMR prevention initiatives since 2018. Through its state-level action plan, Kerala prioritized integration of human and animal AMR surveillance, piloting district-level laboratory strengthening and prescription monitoring in public facilities. Tamil Nadu has implemented structured infection prevention and control programs, while Maharashtra has established district AMR committees linked to medical colleges, enabling periodic resistance reporting and training initiatives, although veterinary AMS implementation remains uneven [29–32].

Although Karnataka's proposed One Health framework under the forthcoming state action plan is commendable, the operational and contextual barriers identified in this study must be addressed for effective implementation at the subdistrict level. Translating policy into practice requires targeted district- and community level strategies to reduce economic barriers and reliance on HPClAs, including government-supported diagnostic subsidies and integration of veterinary diagnostics into national health schemes.

Operationalizing AMS at the district-level

The state AMR division could establish a district veterinary AMS task force comprising deputy directors, senior veterinarians, microbiologists, and pharmacists. This task force could lead stewardship activities, including the development of standard treatment guidelines for common infections, designation of a district laboratory for integrated human–animal AMR testing, identification of AMR hotspots, generation of biannual district antibiograms integrated with INFAAR surveillance, and coordination of AMS training.

This multisectoral integration with the human health sector under the One Health framework represents a novel and implementable model for operationalizing AMS at the district scale.

One Health awareness and training gaps

Despite partial awareness of the One Health concept, understanding of environmental AMR pathways, such as dissemination through animal waste, manure application, and wastewater, remains limited. Transmission risks at the animal–human–community interface were underrecognized. These gaps highlight the need for district-level operational One Health approaches, including mandatory AMS and One Health training every 2–3 years, case-based learning modules, and incorporation of such training into license renewal processes.

The findings are consistent with those reported in other LMICs, where systemic barriers constrain translation of knowledge into practice despite adequate theoretical understanding of AMR. Similar patterns of high knowledge but reliance on empirical therapy due to diagnostic limitations, client pressure, and weak district-level coordination have been reported in Ethiopia, Bangladesh, Nigeria, South Africa, Pakistan, Timor-Leste, and India [33–42]. In contrast, social norms and peer expectations primarily influence antibiotic prescribing behavior in high-income countries such as France and the United Kingdom [43, 44].

Limitations

This study has both strengths and limitations. Although the sample size was limited, 62.7% of veterinarians in the district were included, providing credible representation. Social desirability bias is acknowledged in self-reported KAP; however, qualitative findings substantiate quantitative results. The absence of farmer-level data limits insight into client-driven behaviors and warrants further investigation. Conducted in a single district, generalizability is limited, although findings remain relevant to similar low- and middle-income country settings.

CONCLUSION

This study provides the first district-level assessment of AMS in the veterinary sector in Karnataka, offering critical insights into the current status of AMR awareness, prescribing practices, and systemic barriers. The findings reveal that although veterinarians demonstrate moderate to good knowledge and favorable attitudes toward AMR, these do not consistently translate into rational prescribing practices. A substantial reliance on HPClAs, including enrofloxacin and ceftriaxone, for common conditions such as mastitis and enteritis highlights a significant gap between awareness and implementation of AMS principles.

The study further demonstrates that limited utilization of diagnostic services, despite partial availability, is a key contributor to empirical prescribing. Structural constraints such as inadequate laboratory infrastructure, high diagnostic costs, delays in obtaining results, and workforce shortages strongly influence decision-making in clinical practice. In addition, socioeconomic factors, including client expectations, poor adherence to treatment protocols, and informal access to antibiotics, further exacerbate inappropriate antimicrobial use. These findings collectively indicate that AMS challenges are not solely knowledge-driven but are deeply rooted in systemic, economic, and contextual realities.

From a practical perspective, effective implementation of AMS at the district-level requires context-specific and multisectoral interventions. Mandatory and periodic AMS training programs, integrated with One Health principles, are essential to strengthen applied knowledge and decision-making skills. Improving access to affordable and timely diagnostic services through district-level laboratory strengthening and integration with existing health systems is equally critical. Development and dissemination of locally relevant prescribing guidelines, supported by district antibiograms, can guide rational antibiotic use. In addition, strengthening regulatory mechanisms to control over-the-counter antibiotic access and promoting community level awareness among animal owners are necessary to reduce misuse.

This study has several strengths, including the use of a mixed-methods approach that integrates quantitative and qualitative data to provide a comprehensive understanding of AMS challenges. The inclusion of a substantial proportion of the district veterinary workforce enhances the representativeness and reliability of the findings. However, certain limitations must be acknowledged. The study was conducted in a single district, which may limit generalizability to other regions. Self-reported KAP data may be subject to social desirability bias. Furthermore, the absence of farmer-level data restricts a complete understanding of client-driven influences on prescribing behavior.

Future research should focus on multicentric studies across diverse geographic regions to validate and expand these findings. There is a need to evaluate the effectiveness of targeted AMS interventions, including training programs, diagnostic integration, and policy implementation, at the district and state levels. Incorporating farmer-level KAP assessments will provide a more comprehensive One Health perspective. Longitudinal studies

assessing changes in prescribing behavior and AMR trends following intervention implementation would further strengthen evidence-based policymaking.

In conclusion, this study highlights a critical knowledge–practice gap in AMS within the veterinary sector, driven primarily by systemic and contextual barriers rather than lack of awareness. Addressing these challenges requires a coordinated, district-level approach that integrates training, diagnostics, policy support, and community engagement under a One Health framework. Strengthening AMS at the grassroots level is essential to mitigate AMR and safeguard human, animal, and environmental health.

DATA AVAILABILITY

The supplementary data can be made available from the corresponding author upon request.

AUTHOR'S CONTRIBUTIONS

NM, MV, VKE, and CM: Conceptualization. NM, UB, MV, RR, CM, VKE, GT, SS, and AK: Methodology and study design. NM: Investigation and data collection. NM, RR, AK, VR, CM, JS, and UB: Data analysis and interpretation. NM, RR, VR, and AK: Formal statistical and qualitative analyses. NM, CM, VKE, MV, and UB: Writing – original draft. NM, UB, MV, RR, VKE, GT, AK, VR, JS, SS, and CM: Writing – review and editing. CM, UB, MV, VKE, and RR: Supervision and overall oversight. All authors have read and approved the final version of the manuscript.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

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