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Antibiotic practices and AMR trends in livestock farms of Mymensingh region in Bangladesh

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## Highlights

- Antibiotic use in Bangladesh livestock sector is highly irrational and fragmented.
- Seller qualification and withdrawal knowledge strongly influence dispensing behavior.
- Regression analysis identified key determinants shaping antibiotic selection.
- PCA and clustering revealed distinct antibiotic use profiles across livestock sectors.
- Amoxicillin and tetracycline function as central hub antibiotics in usage networks.

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**Abstract**

**Objective:** In Bangladesh, the unregulated use of antimicrobials in livestock poses a significant threat to the effectiveness of these drugs, yet multi-sectoral data to guide stewardship are scarce. This study investigated veterinary drug use, antibiotic awareness, and risk factors contributing to antimicrobial resistance (AMR) in the Mymensingh region of Bangladesh.

**Methods:** A cross-sectional survey was conducted among livestock farmers (n = 101) and retail pharmacy sellers (n = 104), complemented by veterinary hospital prescription records (n = 330). Field data were collected and descriptive and analytical statistics were conducted in Python to determine predictors of antibiotic choice. Principal Component Analysis (PCA), Hierarchical Clustering, and network analysis were performed to characterize antibiotic usage patterns and co-prescription structures.

**Results:** Provider qualification and knowledge of withdrawal periods significantly influenced antibiotic practices in both farm and pharmacy settings. PCA captured major variance components in farm (41.06%), pharmacy (51.89%), and hospital (40.85%) datasets. Hierarchical Clustering demonstrated sector-specific preferences among 27 antibiotic compounds, with Amoxicillin dominating farm use and Tetracycline-class drugs prevalent in hospital prescriptions. Network analysis revealed tightly connected co-prescription clusters, with Amoxicillin and Tetracycline functioning as central nodes.

**Conclusions:** Significant variation exists in antibiotic awareness and usage across sectors, shaped largely by provider qualification and withdrawal knowledge. The identified predictors

and usage networks provide critical evidence for designing targeted antimicrobial stewardship interventions, highlighting the need for stricter pharmacy regulation and enhanced farmer education.

**Keywords** Antimicrobial resistance (AMR), Veterinary drug use, Livestock, Antimicrobial stewardship, One Health, Bangladesh

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## 1. Introduction

Antimicrobial resistance (AMR) has emerged as a major and rapidly escalating global health challenge, threatening the effectiveness of modern medicine and undermining decades of progress in the prevention and treatment of infectious diseases. A recent systematic analysis by the GBD 2021 Antimicrobial Resistance Collaborators, published in *The Lancet*, reported that in 2021 bacterial AMR was directly responsible for approximately 1.27 million deaths and associated with nearly 4.95 million deaths worldwide. The study further warns that, if effective interventions are not implemented, the global burden of AMR could rise dramatically, with projections suggesting up to 10 million deaths annually by 2050 due to drug-resistant infections [1]. Addressing this challenge requires a One Health approach integrating human, animal, and environmental health [2].

The antimicrobial resistance (AMR) landscape in Bangladesh is characterized by a high prevalence of resistant pathogens, most notably extended-spectrum beta-lactamase (ESBL)-producing *Escherichia coli*, which has become endemic across both clinical and community settings [3]. This crisis is exacerbated by the pervasive misuse of antibiotics in the poultry and livestock sectors, a practice that facilitates the dissemination of resistance through environmental pathways and the food chain [4]. The human health implications are profound; recent estimates from the Institute for Health Metrics and Evaluation (IHME) indicate that in 2021, the number of deaths associated with AMR among individuals aged 70 and above in Bangladesh reached approximately 41,100 [5]. These findings underscore the urgent need for a One Health approach to mitigate the escalating threat of antimicrobial resistance in the region.

The livestock sector is a major contributor to AMR through routine antibiotic use for growth promotion and disease prevention, facilitating resistant bacteria transmission via food, contact, and the environment [6]. In low- and middle-income countries (LMICs) such as Bangladesh, weak regulation, limited surveillance, and widespread non-prescription access to veterinary drugs exacerbate misuse, including incorrect dosing, incomplete courses, and neglect of withdrawal periods [7].

Bangladesh's rapidly expanding livestock sector is essential for food security and rural livelihoods but faces governance challenges. Antibiotic distribution often involves a decentralized network of farmers, drug sellers, feed dealers, paravets, and veterinarians, with limited professional oversight in rural areas [8]. Such fragmented systems increase the risk of inappropriate antimicrobial use and hinder effective stewardship, highlighting the need for coordinated multisectoral interventions [9-11].

This study addresses these gaps through a multi-sectoral assessment of veterinary drug practices and antimicrobial resistance (AMR) risk factors in the Mymensingh region of Bangladesh. The study examines antibiotic use patterns, disease management practices, and sources of veterinary advice across farms, pharmacies, and veterinary hospitals to identify key drivers of antimicrobial misuse and inform targeted antimicrobial stewardship strategies.

## **2. Material and Methods**

### **2.1. Study area**

This cross-sectional study assessed veterinary drug practices and antimicrobial resistance (AMR) risk factors across multiple sectors in the Mymensingh region of Bangladesh. Three Upazilas- Ishwarganj, Mymensingh Sadar, and Purbadhala were selected due to their high density of livestock farms and veterinary service providers, representing an important livestock production zone in the country.

## **2.2. Geographic mapping**

A GIS-based map was developed using QGIS v3.28. The map highlights the three selected Upazilas within Mymensingh, with administrative boundary data obtained from the Bangladesh Bureau of Statistics [12] and the Humanitarian Data Exchange [13]. Data were projected using the WGS 84 coordinate system (EPSG:4326).

## **2.3. Study participants and recruitment**

Participants were recruited from three interconnected components of the livestock value chain: livestock farms, retail pharmacies, and veterinary hospitals (Table 1). A multi-stage sampling approach was employed for recruitment. Livestock farmers (n = 101) were recruited through convenient sampling from the selected Upazilas, targeting both commercial and small-scale poultry and cattle operations. Retail pharmacy sellers (n = 104) were identified through local business registries and recruited via on-site visits to veterinary drug outlets. Veterinary hospital data (n = 330) were obtained through a retrospective review of official clinical records from the Upazila Veterinary Hospitals. Inclusion criteria required farmers to have at least one year of

experience in livestock management and pharmacy sellers to be actively involved in dispensing veterinary drugs.

#### **2.4. Questionnaire development and validation**

A structured questionnaire was developed for this study (Supplementary file 1) through consultation with experts in veterinary medicine, parasitology, and antimicrobial stewardship. The instrument was reviewed to ensure clarity, relevance, and content validity before data collection. It was administered to farmers and pharmacy sellers, while veterinary hospital records were extracted and organized according to the same variables.

#### **2.5. Statistical analysis**

All analyses were conducted in Python v3.10 [14] using commonly used scientific computing libraries including pandas, scipy, statsmodels, scikit-learn, matplotlib, seaborn and numpy. A two-tailed p-value threshold of  $<0.05$  was considered statistically significant.

Descriptive statistics summarized antibiotic use, disease prevalence, and provider categories. For categorical comparisons, Chi-square tests [15] were applied when expected counts were  $\geq 5$ , and Fisher's Exact Test [16] was used for sparse data.

Spearman's rank correlation [17] assessed relationships among indicators of antibiotic awareness, misuse, and AMR risk. Cross-tabulations and heatmap visualizations were used to compare antimicrobial practices across farms, pharmacies, and veterinary hospitals.

Logistic regression [18] examined socio-behavioral predictors of withdrawal period awareness. The dependent variable was knowledge of drug withdrawal periods, with education, information access, and years of experience as predictors. Categorical variables were coded using treatment coding with “Below SSC” and “Low/No” as reference groups. Odds ratios (ORs) with 95% confidence intervals (CIs) were reported, and model convergence confirmed stable parameter estimates.

Principal Component Analysis (PCA) [19,20] was applied separately to farm, pharmacy, and veterinary hospital datasets using standardized variables to explore variability in antimicrobial usage. Hierarchical clustering [21] grouped antibiotics according to similarity in usage profiles across sectors. These analyses were exploratory and used to visualize structural patterns rather than infer causality.

Network analysis was used to map relationships among antibiotics, diseases, and sources. Nodes represented antibiotics, diseases, and sectors, while edges denoted co-occurrence. Degree and betweenness centrality were calculated to identify structurally prominent antibiotics within the antimicrobial use network.

## **2.6. Ethical considerations**

The study involved no animal experimentation or identifiable human data. In accordance with Bangladesh Agricultural University policy and national regulations, formal ethical approval was not required. Participation was voluntary, verbal consent was obtained, and all survey responses and hospital records were anonymized.

### 3. Results

#### 3.1. Antimicrobial use and disease profiles in livestock systems

A total of 535 cases were analyzed across farms (n = 101), veterinary pharmacies (n = 104), and village-level animal health services (n = 330).

At farm level, poultry was the predominant species (60.4%), followed by cattle (29.7%) and goats (6.9%). Major diseases included Mycoplasmosis (14.9%), Newcastle disease (11.9%), Lumpy skin disease (11.9%), and Gumboro (10.9%). Treatments were mainly provided by veterinary surgeons and paravets (each 34.7%). The most frequently used antibiotics were Amoxicillin (31.7%) and Enrofloxacin (20.8%), with 70.3% of farmers reporting adherence to withdrawal periods (Table 2).

At pharmacy level, most outlets were located in Purbadhala (88.5%). Antibiotics were commonly dispensed without prescriptions (91.4%), and record-keeping was rare (93.3%). Ceftriaxone (26.0%) and Amoxicillin (18.3%) were the most frequently sold antibiotics. Ceftriaxone was perceived as most effective (51.0%), though nearly half of respondents (48.1%) reported treatment failures, particularly with Penicillin and Ciprofloxacin (Table 2).

At veterinary hospital level, cattle were the dominant species treated (83.6%). Common conditions included anorexia (22.4%), worm infestation (21.5%), and pneumonia (11.5%). All cases involved antimicrobial treatment, with Sulfadimidine (45.5%) and Oxytetracycline (37.6%) being most frequently prescribed (Table 2).

#### 3.2. Comparative antimicrobial use in farms and hospitals

Antimicrobial use and disease profiles differed markedly between farms and veterinary hospitals (VH). Oxytetracycline and Sulfadimidine were predominantly used in VH cases, whereas Amoxicillin, Ciprofloxacin, Doxycycline, and Enrofloxacin were more common on farms. Ceftriaxone, Ampicillin, and Erythromycin were also more frequent in VH settings, while Gentamicin, Levofloxacin, and Lincomycin were reported only on farms.

Disease patterns also varied, with VH records showing higher incidences of anorexia, pneumonia, dog bites, and worm infestation, whereas farms reported greater frequencies of Mycoplasmosis, Gumboro, and Newcastle disease. Treatment providers differed substantially: VH cases were managed exclusively by veterinary surgeons, while farm treatments involved paravets, farm owners, and drug sellers (Fig. 2).

### **3.3. Correlation analysis of awareness, misuse, and antibiotic resistance indicators**

In farms, provider qualification showed a moderate negative correlation with drug choice ( $r_s = -0.264$ ,  $p = 0.008$ ), suggesting that more qualified providers selected less commonly used antibiotics. Associations between provider qualification and withdrawal knowledge ( $r_s = -0.087$ ,  $p = 0.390$ ) and between drug choice and withdrawal knowledge ( $r_s = -0.167$ ,  $p = 0.094$ ) were weak and not significant (Table 3).

In pharmacies, seller qualification was strongly associated with prescription-based dispensing ( $r_s = 0.488$ ,  $p < 0.001$ ). Qualification also correlated with treatment failure reporting ( $r_s = 0.243$ ,  $p = 0.013$ ) and perceived antibiotic effectiveness ( $r_s = 0.204$ ,  $p = 0.038$ ). Prescription-based dispensing was positively associated with perceived drug efficacy ( $r_s = 0.459$ ,  $p < 0.001$ ).

However, the most frequently sold antibiotics showed no significant correlations with other indicators (Table 4).

### **3.4. Cross-tabulation of drug type by source**

Cross-tabulation revealed substantial differences in antimicrobial use across farms, pharmacies, and veterinary hospitals. Veterinary hospitals contributed the largest number of records ( $n = 330$ ), compared with pharmacies ( $n = 104$ ) and farms ( $n = 101$ ), reflecting differences in reporting intensity and treatment protocols.

Professional qualification appeared to influence prescribing and dispensing practices; however, weak correlations suggest that commercial and practical factors may play a dominant role in antimicrobial use patterns (Fig. 3). Figure 4 further illustrates variations in disease distribution and antimicrobial use across sources.

### **3.5. Determinants of withdrawal awareness**

Multivariable logistic regression showed that none of the evaluated socio-behavioral factors, including education level, information access, or farming experience, were significantly associated with farmers' awareness of antimicrobial withdrawal periods ( $p > 0.05$ ). For example, education above the Secondary School Certificate level had an odds ratio of 1.324 (95% CI: 0.101–17.331), but the association was not statistically significant ( $p = 0.831$ ). Wide confidence intervals indicate substantial variability in the estimates (Table 5).

### **3.6. Hierarchical clustering of antibiotic usage**

Hierarchical clustering identified three main groups of antibiotics based on sectoral frequency distributions (Fig. 5): i) antibiotics concentrated in veterinary hospitals, ii) widely used agents across farms and pharmacies, and iii) low-frequency antibiotics with limited presence across sectors. Short branch distances indicated similar cross-sector usage patterns, whereas longer branches reflected divergence in sectoral concentration.

### **3.7. PCA-based clustering of antibiotic usage profiles**

PCA revealed distinct variance structures across sectors. In farms, PC1 (27.43%) captured variance associated with treatment provider and drug usage variables, while PC2 (13.63%) reflected livestock-type and location variation (Fig. 6A). In pharmacies, PC1 (33.57%) was primarily associated with dispensing practices and documentation variables, whereas PC2 (18.32%) reflected perceived treatment outcomes (Fig. B6). In veterinary hospitals, PC1 (22.62%) captured drug selection variability, and PC2 (18.23%) reflected administrative characteristics (Fig. 6C).

Scatterplots of PC1 and PC2 demonstrated visible separation of subgroups within sectors, indicating heterogeneity in antimicrobial usage profiles. Farms and pharmacies displayed more defined clustering, while veterinary hospitals exhibited broader dispersion, suggesting greater variability in institutional prescribing patterns. These separations represent statistical differentiation in covariance structure rather than evidence of causal drivers of antimicrobial choice.

### **3.8. Factor structure of antimicrobial practices**

Exploratory factor analysis identified latent structures in antimicrobial practices.

In farms, ten factors were retained (eigenvalue  $>1$ ). The first factor represented veterinary surgeon-led treatment (loading = 0.935), while the second reflected owner-led treatment and tetracycline use. Other factors captured patterns associated with fluoroquinolones, oxytetracycline, and sulfonamides (Fig. 7).

In veterinary hospitals, a more complex structure was observed, with 27 factors exceeding the eigenvalue threshold. The first three factors explained substantial variance and reflected clusters related to broad-spectrum antibiotic use, tetracycline versus sulfonamide usage, and disease–treatment associations (Fig. 7).

### **3.9. Network structure of antibiotic use across diseases and service provider**

Network analysis examined relationships among antibiotics, diseases, and service sources (farms, pharmacies, and veterinary hospitals) (Fig. 8). The network contained 89 nodes and 174 edges, representing co-occurrence patterns among 34 antibiotics, 51 diseases, and three service settings.

Amoxicillin and Oxytetracycline showed the highest connectivity, linking multiple diseases across sectors, while Ciprofloxacin also displayed notable associations, particularly with respiratory and gastrointestinal conditions. Antibiotics such as Erythromycin, Penicillin, and Sulfonamides occupied intermediate positions, connecting smaller clusters of diseases and providers.

Source-level patterns indicated more diffuse connectivity in farms and pharmacies, suggesting broader antibiotic usage, whereas veterinary hospital prescriptions were more clustered, particularly around tetracycline and sulfonamide antibiotics. Overall, the network topology

indicates that a limited number of antibiotics dominate treatment practices across diseases and service settings.

The network represents co-occurrence patterns in antimicrobial usage rather than biological resistance mechanisms.

#### 4. Discussion

This multi-sectoral study reveals a complex and fragmented antimicrobial ecosystem in Bangladesh's Mymensingh region, where high usage of Critically Important Antimicrobials (CIAs), significant stewardship gaps, and systemic surveillance biases collectively threaten One Health efforts to contain AMR.

The epidemiological landscape is dominated by preventable diseases like Mycoplasmosis (14.85%), Newcastle Disease (11.88%), and Lumpy Skin Disease (11.88%), linked to intensive farming, poor biosecurity, and inadequate vaccination [22,23]. This high disease burden occurs within a fragmented treatment landscape. While veterinary surgeons and paravets each provide 34.65% of treatments, a concerning 30.69% of interventions are managed by farm owners and local drug dealers [24, 25]. This unsupervised access fuels a heavy reliance on CIAs, with amoxicillin (31.68%), enrofloxacin (20.79%), and ciprofloxacin (9.9%) dominating farm use, and ceftriaxone (25.96%) being prevalent in pharmacies [26,27]. The routine, often prophylactic use of these last-resort drugs for common conditions critically erodes the future veterinary therapeutic arsenal, posing a direct threat to both animal and human health. This is exacerbated by pharmacy practices, where 91.35% of antibiotics are dispensed without prescription and 48.08% of sellers report treatment failures [27]. Concurrently, veterinary hospitals rely on

empirical, broad-spectrum treatments with sulfadimidine (45.45%) and oxytetracycline (37.58%) due to limited diagnostic infrastructure [28,29].

Our comparative analysis uncovered fundamental contextual disparities between farm and veterinary hospital (VH) settings. VHS predominantly manage complex, referred cases (e.g., anorexia, dog bites), while farms grapple with endemic production diseases (e.g., Mycoplasmosis, Gumboro) [30]. This epidemiological divide, coupled with a pronounced source-level bias where VHS contributed 330 records versus 104 from pharmacies and 101 from farms, highlights a critical flaw in current surveillance. National AMR systems relying solely on institutional VH data will systematically underestimate the resistance drivers circulating in the broader livestock population, necessitating integrated One Health surveillance that captures data from all parallel veterinary ecosystems [31].

The behavioural drivers of AMR also varied significantly by sector. In farms, qualified providers were significantly more likely to avoid commonly misused antibiotics ( $r_s = -0.264$ ,  $p = 0.008$ ), yet their qualification did not translate to better knowledge of withdrawal periods [32]. This indicates that training improves drug selection but fails to address food safety compliance. In contrast, pharmacy-level data revealed that seller qualification was strongly correlated with prescription-based dispensing ( $r_s = 0.488$ ,  $p < 0.001$ ) and awareness of treatment failures [33]. This provides a clear mandate for policy: instead of unenforceable blanket bans, a tiered licensing system should be implemented where trained paravets or certified sellers can dispense a limited list of lower-tier antibiotics, while all CIAs remain strictly veterinarian-prescribed. This approach leverages the existing workforce to maintain animal health access while enforcing stewardship.

The lack of statistical significance across all examined predictors ( $p > 0.05$ ) suggests that withdrawal awareness may be influenced by factors beyond traditional socio-demographic variables. While the odds ratio for higher education (Above SSC vs. Below SSC: OR = 1.324) hinted at a positive trend, the wide confidence interval (95% CI: 0.101–17.331) underscores the high variability and lack of precision in this association. This aligns with recent observations in peri-urban farming systems where knowledge of antimicrobial resistance and withdrawal periods remains low regardless of formal education levels [34]. The low Pseudo R-squared (0.02871) and non-significant LLR p-value (0.4737) further confirm that the current model captures only a negligible fraction of the variance in awareness. This discrepancy may be attributed to "knowledge-action gaps," where farmers may possess general information but lack the specific, technical understanding required to implement withdrawal periods effectively [34].

Alternatively, information access categorized as "Moderate/High" may still lack the quality or specificity needed to impact awareness, as drug sellers and feed vendors often the primary sources of information for smallholders, may prioritize sales over public health safety [35].

Advanced analytics provided a strategic roadmap for targeted interventions. Hierarchical clustering identified distinct "intervention units," such as a cluster of veterinary-dominant antibiotics (Sulfadimidine, Oxytetracycline) for VH-specific guideline audits, and a cluster of broad-spectrum agents (Ciprofloxacin, Doxycycline) shared by farms and pharmacies for cross-sectoral supply chain regulation [36,37]. Principal Component Analysis further illuminated operational heterogeneity within each sector, revealing distinct farm and pharmacy archetypes defined by management practices and compliance levels, confirming that these sectors are not monoliths and require nuanced interventions [38-40]

The latent drivers of drug use, uncovered through Exploratory Factor Analysis, contrasted sharply between settings. The farm dataset exhibited a simpler structure centred on treatment authority (owner vs. professional), while the VH dataset revealed a complex latent space where drug choices were tightly linked to specific disease syndromes [41]. This fundamental difference between community-level autonomy and clinical complexity necessitates tailored stewardship strategies.

Most critically, the network analysis reveals a highly concentrated antimicrobial usage landscape, where a few broad-spectrum antibiotics notably Amoxicillin and Oxytetracycline, function as structural hubs. Their high connectivity across numerous diseases and institutional settings signifies their role as the dominant drivers of antimicrobial exposure in this ecosystem. This finding is critical, as the structural centrality of these agents suggests they are not just frequently used but are also the primary conduits of selective pressure across the entire network [42]. Furthermore, the analysis identified distinct, sector-specific prescribing patterns. The diffuse connectivity within farm and pharmacy networks points toward broader, less specialized usage, whereas the clustered patterns in veterinary hospitals suggest more protocol-driven therapeutic choices. This structural divergence underscores that effective antimicrobial stewardship (AMS) must be tailored to the specific context of each sector rather than applying a uniform strategy [43]. Therefore, stewardship efforts such as mandating sensitivity testing or promoting alternatives focused on these hub drugs would have a disproportionately high impact on slowing AMR emergence across the entire system, a core objective of the One Health approach [44].

In summary, the fundamental challenge extends beyond the mere reliance on CIAs to the pervasive irrationality of antibiotic choice, driven by a fragmented provider network and weak regulation. Our data-driven identification of sector-specific usage clusters and system-wide hub antibiotics provides a clear, evidence-based roadmap for prioritizing stewardship interventions where they will have the greatest impact on preserving antimicrobial efficacy for both animal and human health.

### **Limitation**

The multivariate (PCA, clustering, factor analysis) and network-based approaches employed in this study were exploratory and descriptive in nature. These methods identify covariance structures, similarity groupings, and connectivity patterns within cross-sectional antimicrobial usage data. They do not establish causal pathways, transmission directionality, resistance gene dissemination, or temporal dynamics.

Because microbiological susceptibility testing, genomic resistance profiling, and longitudinal surveillance were not incorporated, structural prominence within the network should not be equated with confirmed AMR spread. Future research integrating phenotypic and genotypic resistance data will be necessary to evaluate how usage connectivity relates to resistance evolution and dissemination.

## Conclusion

In conclusion, the fundamental challenge in Bangladesh's livestock sector is not merely the reliance on CIAs, but the pervasive irrationality and poor predictability of antibiotic choice, driven by a fragmented provider network and weak regulation. Our data-driven identification of sector-specific usage clusters and system-wide hub antibiotics provides a clear, evidence-based roadmap for prioritizing stewardship where it will have the greatest impact. Mitigating AMR risks requires integrated One Health surveillance and coordinated, context-specific interventions that address the unique drivers in each sector of this fragmented ecosystem.

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**Ethical approval:** Not required

## Acronyms:

AMR: Antimicrobial resistance

CIAs: Critically Important Antimicrobials

CI: Confidence interval

EFA: Exploratory Factor Analysis

FMD: Foot-and-mouth disease

LMICs: Low- and Middle-Income Countries

LSD: Lumpy skin disease

NMDS: Non-metric multidimensional scaling

OR: Odds Ratio

PCA: Principal Component Analysis

VHs: Veterinary hospitals

WHO: World Health Organization

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**Table 1.** Multisectoral data collection from farms, pharmacies, and veterinary hospitals.

<b>Sector</b>	<b>Sample size (n)</b>	<b>Data collection method</b>	<b>Key data points collected</b>
<b>Livestock farms</b>	101	Structured questionnaire administered to farmers	Livestock type, disease status, treatment practices, antibiotic usage, and knowledge of drug withdrawal periods.
<b>Retail pharmacies</b>	104	Structured questionnaire administered to pharmacy sellers	Seller qualification, dispensing practices (prescription vs. non-prescription), most frequently sold antibiotics, and perceived drug effectiveness.
<b>Veterinary Hospitals (VH)</b>	330 (Records)	Retrospective review of hospital records	Demographic details, disease records, and drug prescription profiles.

**Table 2.** Summary of farm-, pharmacy-, and veterinary hospital-level indicators on livestock types, disease occurrence, treatment sources, and antibiotic use in Mymensingh region

Category	Variable	Most frequent responses with frequency (%)
<b>Farm-level indicators</b>	Upazila	Purbadhala (62.4%), Mymensingh Sadar (23.8%), Ishwarganj (13.9%)
	Types of animals	Poultry (60.4%), Cattle (29.7%), Goat (6.9%)
	Common diseases	Mycoplasmosis (14.9%), Newcastle disease (11.9%), Lumpy skin disease (11.9%), Gumboro (10.9%)
	Treatment providers	Veterinary surgeon (34.7%), Paravet (34.7%)
	Generic drugs used	Amoxicillin (31.7%), Enrofloxacin (20.8%)
	Knowledge of withdrawal	Yes (70.3%), No (20.8%)
	<b>Pharmacy-level indicators</b>	Seller qualification
Location		Purbadhala (88.5%), Mymensingh Sadar (11.5%)
Prescription practice		Sometimes (91.4%)
Most sold antibiotics		Ceftriaxone (26.0%), Amoxicillin (18.3%)

	Record keeping	No (93.3%)
	Effective antibiotics	Ceftriaxone (51.0%), Gentamicin (9.6%)
	Treatment failure antibiotics	Penicillin (16.4%), Ciprofloxacin (16.4%)
<b>Veterinary hospital indicators</b>	Upazila	Kendua (100%)
	Types of farms	Cattle (83.6%)
	Common diseases treated	Anorexia (22.4%), Worm infestation (21.5%), Dog bite (11.8%), Pneumonia (11.5%), LSD (11.2%)
	Prescribed drugs	S.Pben (44.9%), Etracin (36.7%)
	Generic drugs used	Sulfadimidine (45.5%), Oxytetracycline (37.6%)
	Drug type	Antimicrobial (100%)

**Table 3.** Spearman's rank correlation matrix (rs) for farm setting indicators.

<b>Indicator</b>	<b>Treated by</b>	<b>Generic Name of Drugs</b>	<b>Knowledge of Withdrawal Period</b>
<b>Treated by</b>	1.000	-0.264*	-0.087
<b>Generic Name of Drugs</b>	-0.264*	1.000	-0.167
<b>Knowledge of Withdrawal Period</b>	-0.087	-0.167	1.000

\*Significant at  $p < 0.01$ . P-values: Treated by vs. Generic Name ( $p = 0.008$ ); Generic Name vs. Withdrawal Period ( $p = 0.094$ ); Treated by vs. Withdrawal Period ( $p = 0.390$ ).

**Table 4.** Spearman's rank correlation matrix (rs) for pharmacy setting indicators.

<b>Indicator</b>	<b>Qualification</b>	<b>Prescription</b>	<b>Most Sold AB</b>	<b>Works Well</b>	<b>Treatment Failure</b>
<b>Qualification of Pharmacy Seller</b>	1.000	0.488***	-0.033	0.204*	0.243**
<b>Sell with or without Prescription</b>	0.488***	1.000	0.052	0.459***	0.143
<b>Most Sold Antibiotics</b>	-0.033	0.052	1.000	0.076	-0.043
<b>Which Antibiotic Works Well</b>	0.204*	0.459***	0.076	1.000	-0.090

<b>Treatment Failure</b>	0.243**	0.143	-0.043	-0.090	1.000
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**with Antibiotics**

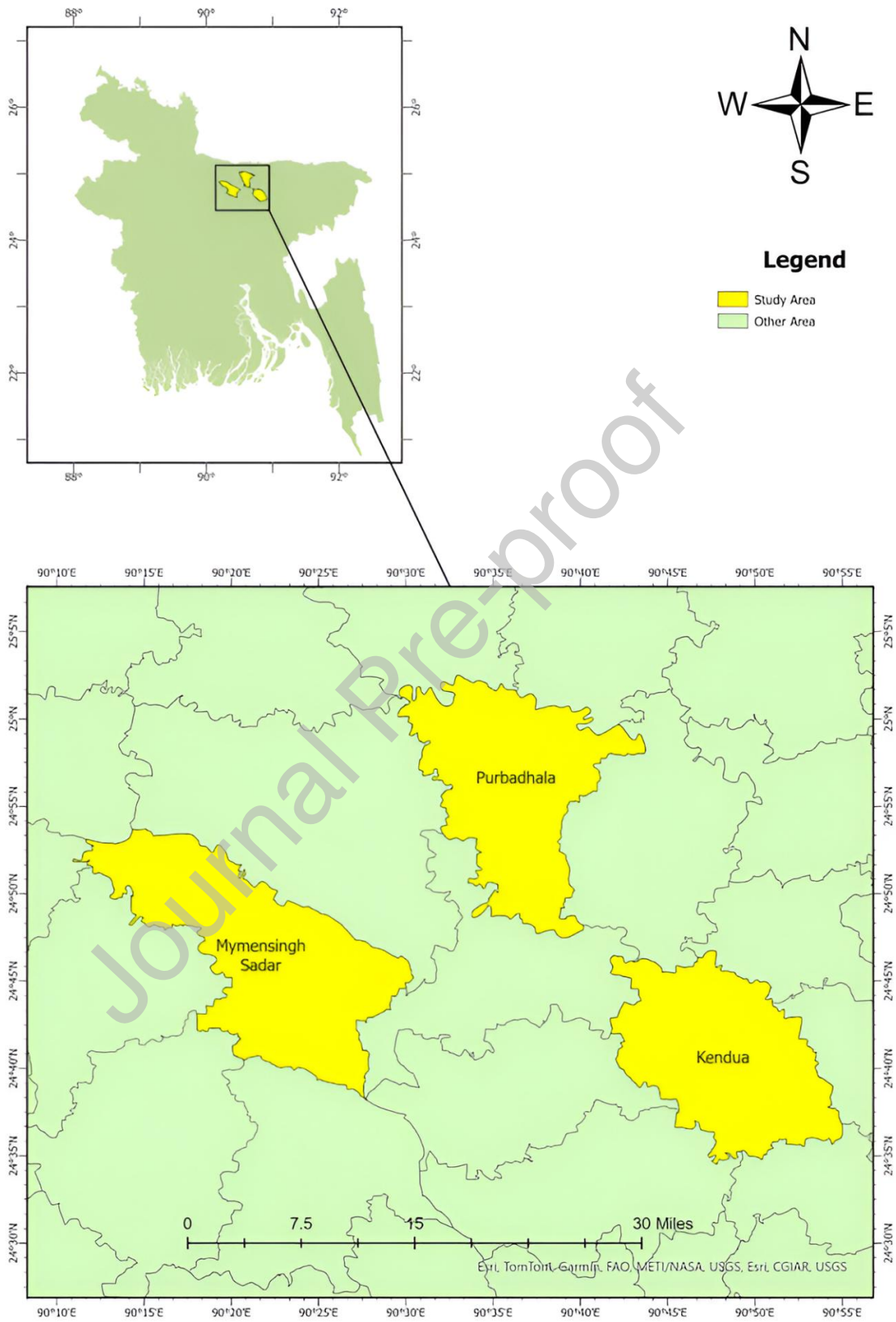
Significance: \*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ , \*  $p < 0.05$ . P-values: Qualification vs. Prescription ( $p = 1.51 \times 10^{-7}$ ); Qualification vs. Works Well ( $p = 0.038$ ); Qualification vs. Treatment Failure ( $p = 0.013$ ); Prescription vs. Works Well ( $p = 1.52 \times 10^{-6}$ ). All other correlations were non-significant ( $p > 0.05$ ).

**Table 5.** Logistic regression results for predictors of withdrawal awareness

Predictor	Coefficient	Std. Error	z-score	P> z	Odds Ratio (OR)	95% CI	
						Lower	Upper
<b>Intercept</b>	0.4788	0.457	1.047	0.295	1.614	0.658	3.955
<b>Education:</b> Above SSC vs Below SSC	0.2807	1.312	0.214	0.831	1.324	0.101	17.331
<b>Education:</b> SSC vs Below SSC	-0.5656	0.719	-0.786	0.432	0.568	0.140	2.303
<b>Info Access:</b> Moderate/High vs Low/No	0.8676	0.756	1.148	0.251	2.381	0.541	10.474
<b>Experience</b> (Years)	0.0592	0.108	0.549	0.583	1.061	0.859	1.309

**Figure Legends**

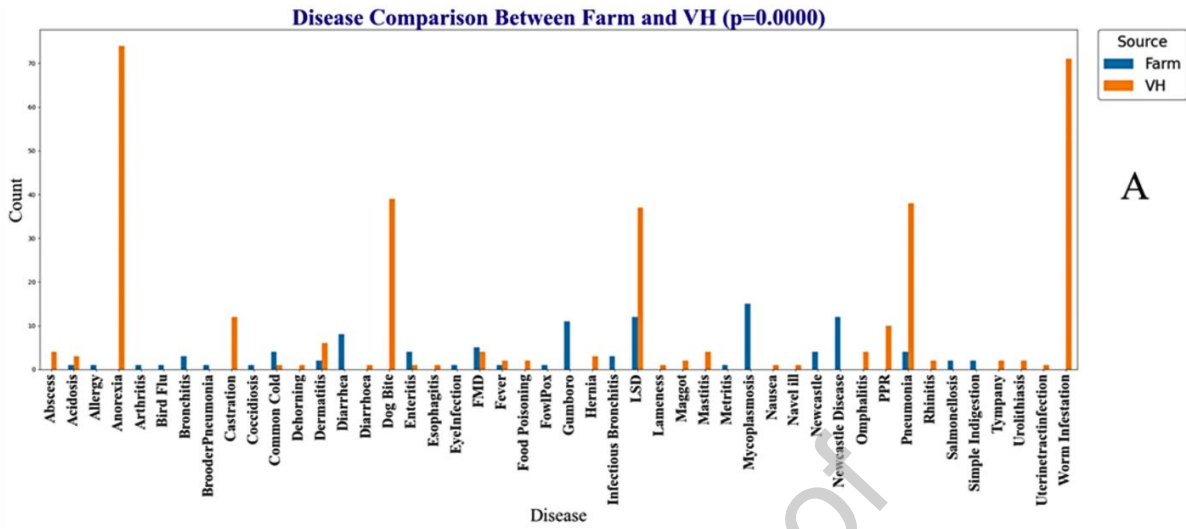
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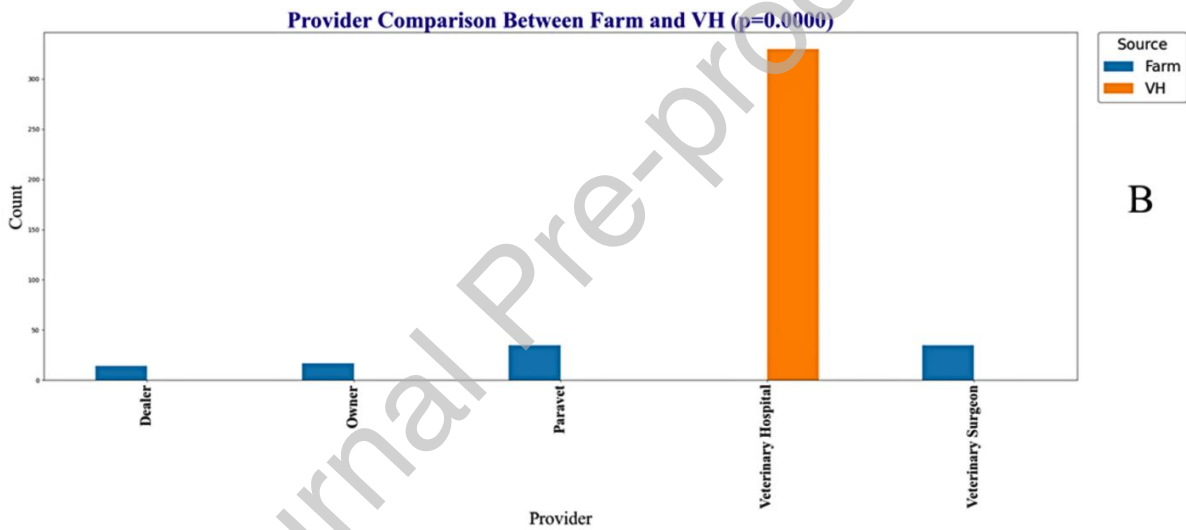
**Fig. 1.** Study area (Purbadhala, Mymensingh Sadar, and Kendua (yellow)), Bangladesh.

Data sources: Bangladesh National Atlas, USGS, ESRI, and CGIAR. The map highlights the three surveyed Upazilas (Purbadhala, Mymensingh Sadar, and Kendua), illustrating the study's focus on a key agricultural hub.

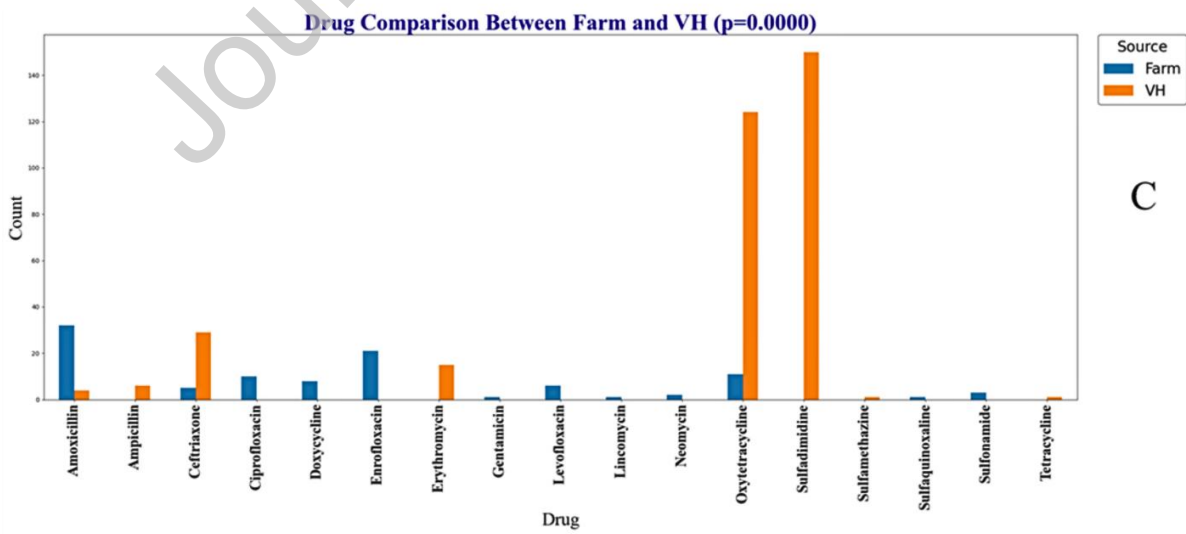
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A



B

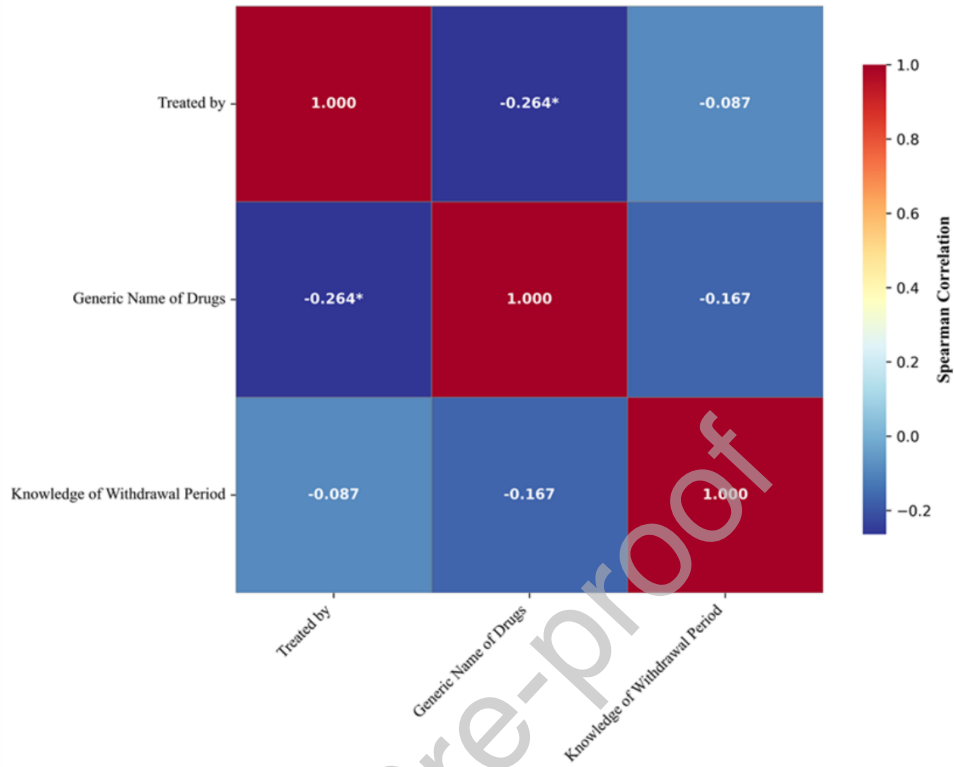


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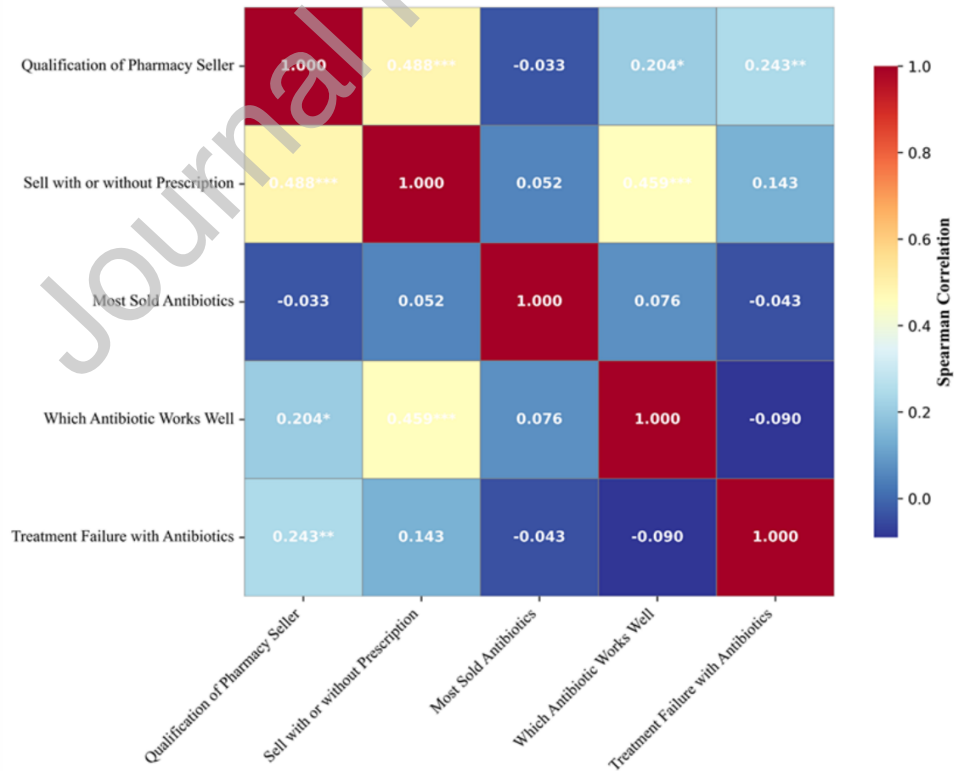
**Fig. 2.** Distinct operational contexts and antimicrobial use landscapes between farm and veterinary hospital (VH) settings. Comparative analysis reveals (A) a divergence in dominant disease burdens, (B) a clear dichotomy in antibiotic preferences, and (C) a fragmented treatment provider network on farms versus exclusive veterinary care in VHS.

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**A Farm Data: Awareness–Misuse–Resistance Correlation (Custom)**

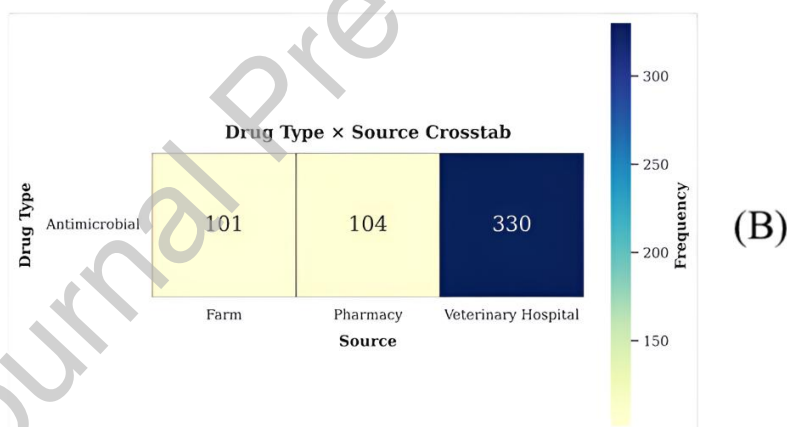
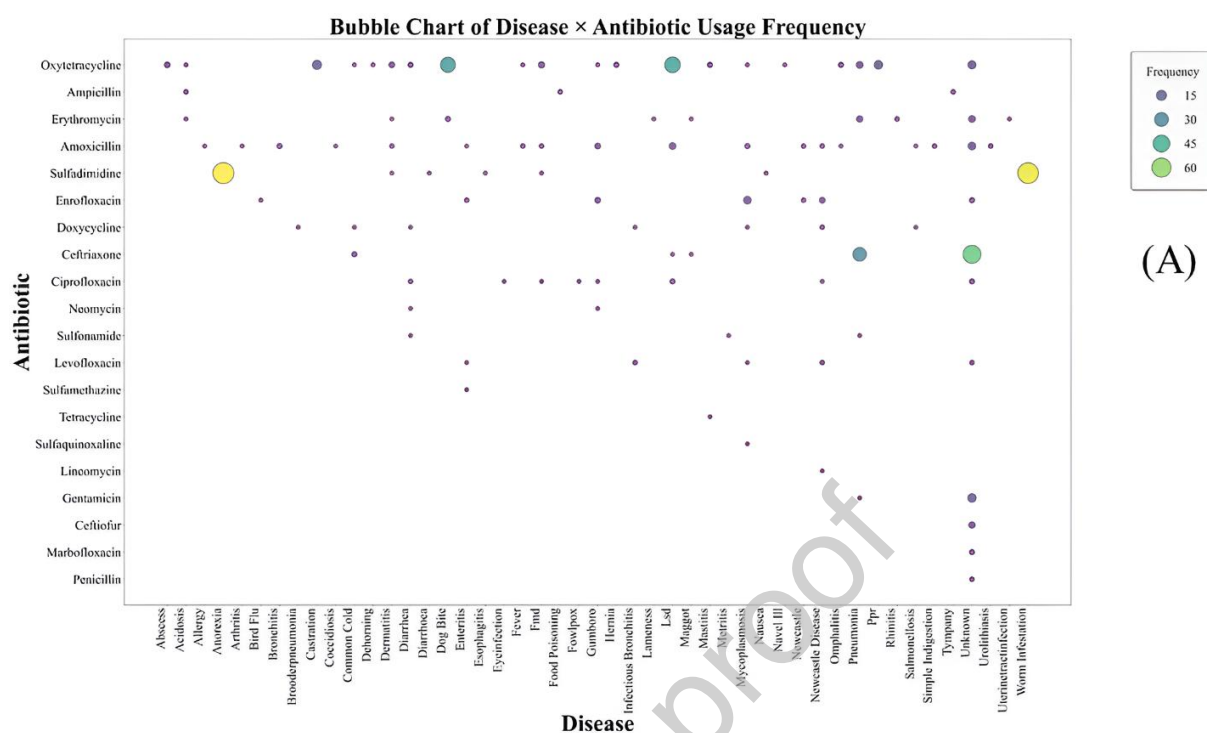


**B Pharmacy Data: Awareness–Misuse–Resistance Correlation (Custom)**

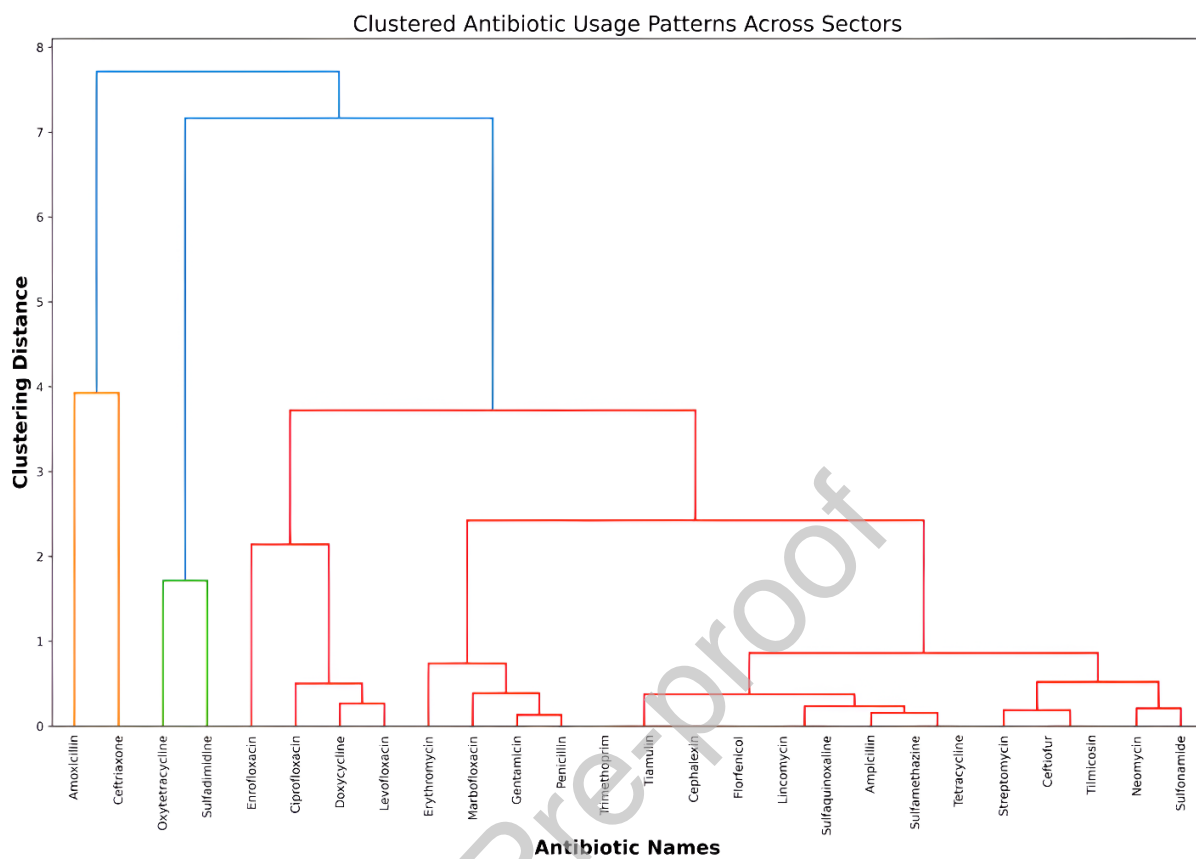


**Fig. 3.** Spearman's correlation heatmaps of antibiotic awareness, misuse, and resistance indicators in farm and pharmacy settings. Professional qualification shapes antibiotic practices and AMR risks differently across sectors. In farms, more qualified providers significantly avoid commonly misused antibiotics, while in pharmacies, higher seller qualification strongly predicts prescription-based dispensing and recognition of treatment failures.

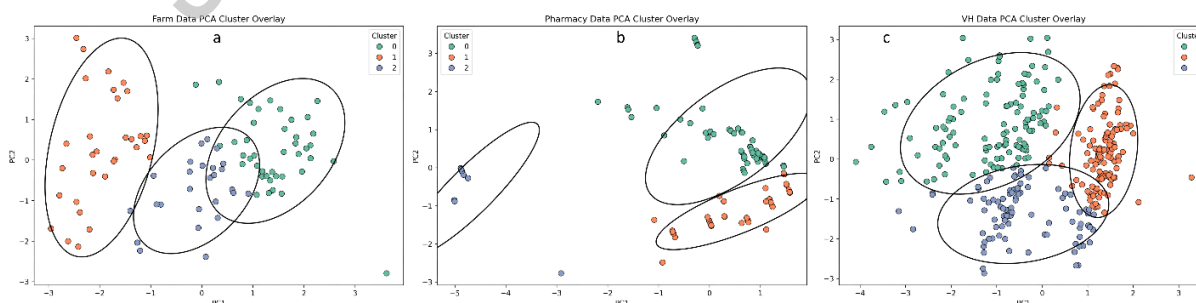
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**Fig. 4.** Source-specific biases and disease-specific usage patterns reveal critical gaps in antimicrobial surveillance. The skewed distribution of records, dominated by veterinary hospital data, demonstrates a systemic surveillance blind spot for community-level usage. Concurrently, the frequent application of broad-spectrum antibiotics across diverse syndromes points to widespread empirical use and a lack of targeted therapy, elevating the risk for cross-resistance.

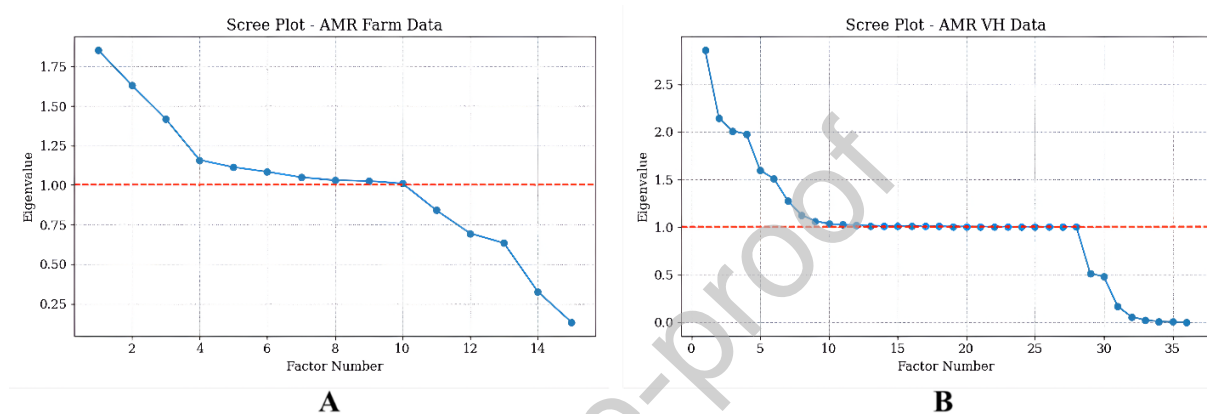


**Fig. 5.** Hierarchical dendrogram illustrating similarity among antibiotics based on cross-sector usage frequency distributions. Branch length represents statistical distance in usage patterns. Clusters denote structural similarity derived from frequency data and do not imply shared resistance mechanisms or causal relationships.



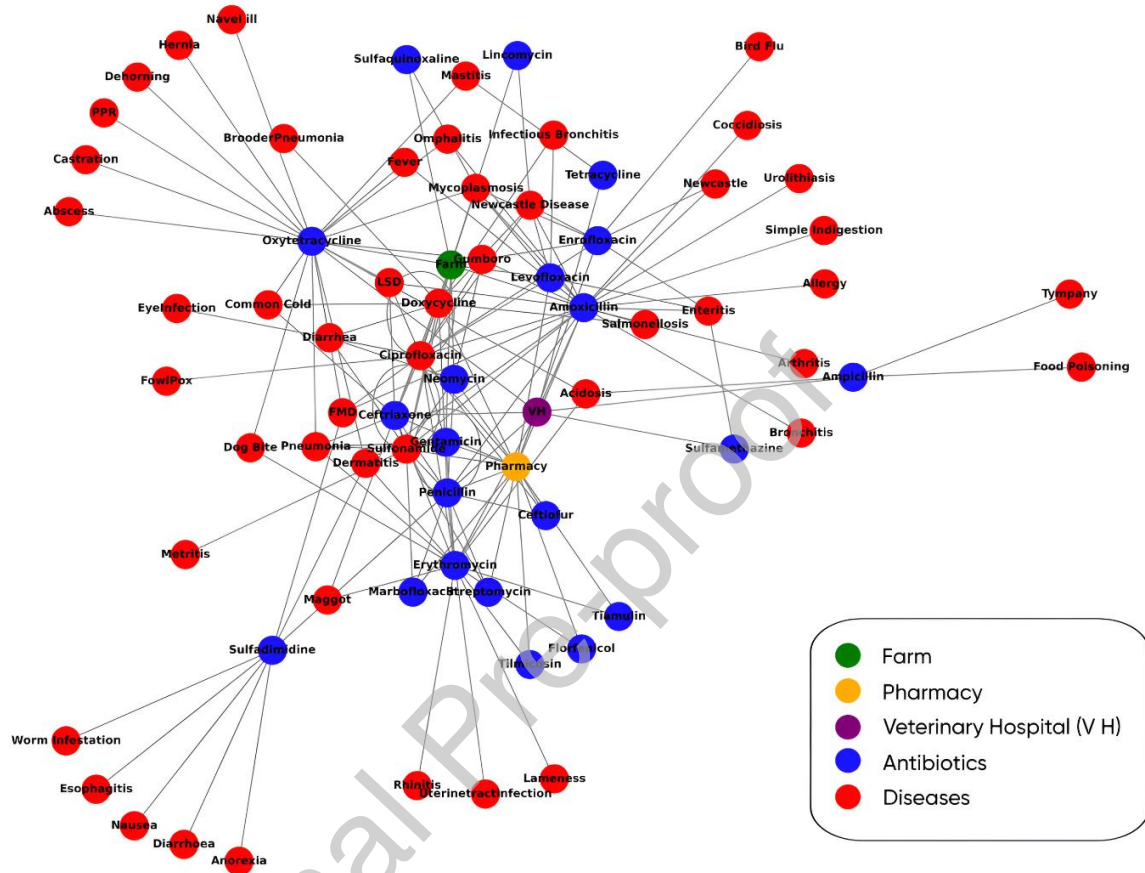
**Fig. 6.** Principal Component Analysis plots illustrating multivariate variance structure of

antimicrobial usage in (a) farms, (b) pharmacies, and (c) veterinary hospitals. PC1 and PC2 represent the largest orthogonal components of explained variance. Clusters reflect statistical separation in usage profiles derived from covariance structure and do not imply causal determinants or predictive relationships.



**Fig. 7.** Exploratory factor analysis reveals a fundamental contrast in the drivers of antimicrobial use between field and clinical settings. The farm dataset's simpler, 10-factor structure reflects treatment behaviors driven by owner autonomy and specific drug access. In stark contrast, the veterinary hospital's complex 27-factor structure captures the multidimensionality of clinical decision-making, where drug choices are tightly linked to specific disease syndromes.

## AMR Interaction Network



**Fig. 8.** Network maps of 89 nodes and 174 edges across antibiotics, diseases, and sources (farm, pharmacy and veterinary hospital). Note that these variables were colour-coded: antibiotics (blue); diseases (red); and sources [farm (green); pharmacy (orange) and veterinary hospital (purple)]. Node size reflects degree centrality, and edge thickness indicates interaction strength.