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Mastitis-Associated Antimicrobial Resistance in Sheep and Goats: A review of Risk Factors, and Environmental Transmission Pathway

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ABSTRACT
Antimicrobial resistance (AMR) is a global health threat affecting both human and animal sectors. Resistance occurs when microorganisms, such as bacteria, viruses, fungi, or parasites, become insensitive to antimicrobial agents to which they were previously sensitive at the recommended dosage, often due to misuse. Pathogens transfer resistance genes among themselves via transformation, conjugation, and transduction, thereby facilitating the spread of infection and complicating treatment. Mastitis is an inflammatory condition of the mammary gland that occurs following injury or disruption of the udder's natural protective barriers, such as trauma, environmental factors, or infectious agents. In small ruminants, particularly sheep and goats, mastitis remains an important health challenge affecting animal welfare, milk production, and farm profitability and hence, prone farmers to antimicrobial use and abuse. Several bacterial pathogens have been implicated in mastitis, with *Staphylococcus aureus* (*S. aureus*) and *Streptococcus agalactiae* (*S. agalactiae*) among the opportunistic microorganisms commonly reported as causative agents. The disease may occur in either clinical or subclinical forms, with subclinical mastitis often remaining undetected due to the absence of obvious clinical signs. Awareness of AMR among small ruminant farmers remains limited, and the indiscriminate use of antimicrobials for both prophylactic and therapeutic purposes has contributed to the emergence and spread of resistant bacterial strains. In addition, management practices, including poor environmental sanitation or contamination, facilitate the transmission of mastitis-causing pathogens among animals, humans, and the environment. Due to limited access to professional veterinary services, the prevalence and distribution of mastitis and agents in small ruminants remain poorly documented.

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INTRODUCTION

A significant development in the healthcare sector was the discovery of antibiotics, which are commonly used to treat, prevent, and control infectious diseases caused by microorganisms Adedeji W. A. (2016). Many infections, especially epidemics that posed a major threat to human life and were reported to have caused high animal mortality, have been put under control following the use of antibiotics (Rahman *et al.*, 2022). However, the abuse and misuse of these agents for bacterial infections caused by *Staphylococcus aureus* (*S. aureus*) have led to the development of superbugs, which are estimated to cause about 10,000,000 deaths per year by 2050 if not addressed (Salam *et al.*,2023).

Antimicrobial Resistance (AMR) has been identified as one of the most serious global health challenges among humans, animals, plants, and the environment, due to the emergence, spread, and persistence of multidrug-resistant (MDR) bacteria, also known as "superbugs" (WHO, 2023; FAO/OIE/WHO, 2021; FAO, 2016). It occurs when bacteria, viruses, fungi, and other parasites fail to respond to drugs to which they were previously sensitive, due to inappropriate use, inadequate dosing, non-adherence to treatment guidelines, or overuse, making treatment of infections difficult (Kallu *et al.*, 2024).

Small ruminant production plays a significant role in livestock production, especially in Nigeria, where rural dwellers rear them for meat, milk, skin, and wool (Yusuf *et al.*, 2018). Small ruminant production among the Hausa (Northerners) is described as a compound system in which small herds of goats are kept in their compounds and fed silage during the rainy season, and sheep are also allowed to graze with cattle (Williamson & Payne, 1978).

Mastitis is one of the most important bacterial diseases affecting dairy small ruminants (sheep and goats) worldwide and remains a major indication for antimicrobial use in both clinical and subclinical cases. It causes substantial economic losses through reduced milk yield (10–40% in clinical cases), treatment costs, milk withdrawal during therapy, premature culling, and mortality in severe infections, as well as indirect losses such as reduced reproductive performance, lower kidding/lambing rates, and poor growth of suckling offspring (Contreras & Rodríguez, 2011). In addition, other bacterial diseases in small ruminants, including pasteurellosis (*Mannheimia haemolytica*, *Pasteurella multocida*), colibacillosis (*Escherichia coli*), caseous lymphadenitis (*Corynebacterium pseudotuberculosis*), and foot rot (*Dichelobacter nodosus* with *Fusobacterium necrophorum*), also require antimicrobial intervention; however, mastitis remains the most significant due to its high prevalence, chronicity, and frequent subclinical presentation.

The extensive, often empirical, use of antimicrobials in mastitis treatment significantly contributes to AMR. Repeated or inappropriate antibiotic use, especially in undiagnosed subclinical cases, exerts selective pressure on pathogens such as *Staphylococcus aureus* and *Streptococcus* spp., promoting the emergence and spread of multidrug-resistant strains. This is further compounded by limited veterinary oversight and unrestricted access to drugs in many smallholder systems, increasing the risk of residues, treatment failures, and the transmission of resistant organisms across the animal–human–environment interface.

In response, there is growing adoption of non-antibiotic alternatives to reduce antimicrobial dependency. These include improved hygiene and milking practices, antiseptic teat dipping, vaccination, probiotics, phytotherapeutics, selective dry cow therapy, and enhanced housing management, all of which help reduce infection pressure and disease incidence.

This review, therefore, aims to critically evaluate mastitis as a major driver of antimicrobial use in small ruminants, assess its risk factors and its contribution to AMR development, examine associated bacterial pathogens, and the implications on public health.

Antimicrobial Resistance and Its Biological Basis

In bacteriology, as it pertains to livestock diseases, particularly mastitis, it refers to the ability of microorganisms to survive and replicate in the presence of antimicrobial agents to which they are previously susceptible, either by killing them or inhibiting their growth (Mala *et al.,* 2021). The WHO has emphasised that it evolved naturally over time through genetic changes but has increased over the years due to the misuse and overuse of antimicrobials in humans, animals, and agriculture (WHO, 2023).

Mechanisms of Antimicrobial Resistance Development in Bacteria

Resistance of microorganisms, particularly bacteria, to antimicrobial agents occurs through four mechanisms.

The enzymatic inactivation of antimicrobials by the production of enzymes that destroy active compounds in the agents or chemically modify them, such as beta-lactamases that hydrolyse the beta-lactam ring in penicillins and cephalosporins, rendering them inactive. In the livestock sector, extended-spectrum beta-lactamases (ESBLs)-producing *Escherichia coli* and *Klebsiella pneumoniae* have been recovered from cases of mastitis and from healthy animals (Geser *et al.,* 2012).

Target modification is the second mechanism and involves altering the antimicrobial target molecule on the bacteria, thereby reducing binding affinity. This can be seen in methicillin-resistant *Staphylococcus aureus* (MRSA), which carries the *mecA* gene encoding penicillin-binding protein 2a (PBP2a), thereby reducing affinity for beta-lactam antimicrobial agents and conferring broad-spectrum resistance within the class (Mlynarczyk-Bonikowska *et al.,* 2022).

Also, a reduction in antimicrobial permeability through alterations in bacterial outer membrane porins or through upregulation of efflux pumps, lowering intracellular antimicrobial concentrations below a potent threshold (Fernández & Hancock, 2012). The efflux pumps are widely distributed across bacterial taxa and confer resistance to structurally diverse antimicrobial agents, such as tetracyclines, fluoroquinolones, and macrolides (Brauner *et al.,* 2016). *Pseudomonas aeruginosa* and other Gram-negative bacteria use sophisticated multidrug efflux systems to confer high-level multidrug resistance (Bera *et al.,* 2012).

Target bypass or production of alternative metabolic pathways that surround the target site of antimicrobials or produce proteins that prevent agents from binding to the target site, an example is the ribosomal protection of proteins that displace tetracycline from ribosomes in *Tet*(M) and *Tet*(O) distributed in *Streptococci* and *Staphylococcal* associated mastitis (Li *et al.,* 2013).

One factor contributing to antibiotic resistance has been identified as the presence of antibacterial residues in animal-derived foods, particularly in Nigeria, where farmers frequently self-medicate their livestock and antibiotic use is not controlled or supervised. Thus, a common cause of antibiotic treatment failures in food animals (Ji *et al.,* 2023). AMR can spread from the environment through vertical and horizontal gene transfer by way of mutation, recombination, and the resistant genes are often transferred to pathogenic bacteria within the environment, which further gets to humans by consumption/exposure to animals or animal products such as milk, meat, eggs containing residue of antibiotics (Kallu *et al.,* 2024).

Genetic Mutations

Bacterial horizontal gene transfer (HGT) depends on mobile genetic elements (MGEs), which also facilitate organismal evolution and rapid adaptation (Tokuda, & Shintani, 2024). MGEs consist of bacteriophages, transposons, insertion sequences, plasmids, and integrative and conjugative elements (Tokuda, & Shintani, 2024).

Horizontal Gene Transfer

Bacteria evolve and adapt largely through HGT via transformation, transduction, conjugation, and outer membrane vesicles. Other transfer mechanisms are driven by mobile genetic elements (MGEs). These are segments of DNA capable of autonomous movement, either within the same cell (intracellularly) or between entirely different cells (intercellularly) (Tokuda, & Shintani, 2024).

Examples of MGEs include Conjugative DNA elements (plasmids), transposable DNA elements (transposons and integrons), integrative and conjugative elements (ICEs), and bacteriophages (reference). They act as the primary evolutionary drivers of AMR by facilitating the rapid, intra- and intercellular dissemination of antimicrobial resistance genes (ARGs) through HGT (Partridge *et al.,* 2018). Within this complex genetic ecosystem, conjugative plasmids serve as autonomous, extrachromosomal vehicles that physically bridge bacterial cells, distributing multidrug-resistant traits across diverse species and geographic borders (Hossain *et al.,* 2026). Intracellular logistics are orchestrated by transposable DNA elements: transposons actively cut and paste ARGs between stationary bacterial chromosomes and mobile plasmids, while integrons function as static capture platforms that utilise site-specific recombinases to stack individual, functional resistance cassettes into multidrug-resistant blocks. Bridging these functionalities, integrative and ICEs mimic transposons by integrating directly into the host’s primary chromosome for stable, long-term lineage transmission, yet they retain the ability to excise themselves and transition into circular, plasmid-like conjugative shuttles to infect neighbouring cells (da Silva *et al.,* 2022). Furthermore, bacteriophages expand this network into the surrounding environment by inadvertently encapsulating host bacterial ARGs within their capsids during replication, thereby shielding the genetic cargo from external degradation and delivering resistance traits over large spatial scales via viral transduction. Together, this network captures, organises, and moves ARGs by continually fuelling the rise of dangerous superbugs.

In a study by Tokuda & Shintani (2024), plasmids are circular or linear extrachromosomal replicons that transmit genes among bacteria via conjugation (Tokuda & Shintani, 2024). It is not possible to inherit different plasmids from the same cell line because of their shared Incompatibility group (*Inc* group), which prevents their coinheritance. Plasmids of *Enterobacteriaceae*, *Pseudomonas* and *Staphylococci* and *Enterococci* contain *inc*A to *inc*Z, *inc*P-1 to P-14 and *inc*1 to *inc*18, respectively.

Integrons are made up of the integron-integrase gene (*int*I1), a recombination site (*att*I), and a promoter (Pc) in the inner region of intI1, which are key elements in the transfer of ARGs among bacteria, though unlike transposons and chromosomally integrated MGEs (ciMGEs), which also have genetic elements, they can quickly accumulate and spread ARGs among bacteria by housing different gene cassettes within a single structure (Alhaji & Isola, 2018).

Transposons are genetic elements that can be inserted between replicons using the enzyme transposase, though they must first be integrated into a plasmid or ICE before they can be transferred between cells by transposition (Bhat *et al.,*2023).

Distinction between Intrinsic and Acquired Resistance

Intrinsic resistance is the chromosomally encoded characteristic of a bacterium that makes it naturally insensitive to a particular class of antimicrobial agents, irrespective of prior exposure (Oliveira *et al.,*2024). The resistance is not transmissible between species, non-predictable, and doesn't result from selective pressure. An example is the intrinsic resistance of all Gram-negative bacteria to glycopeptides such as vancomycin, due to the outer membrane's permeability barrier (Blair *et al.,* 2015).

Acquired resistance differs from intrinsic resistance because it occurs in bacteria that were previously susceptible to an antimicrobial agent (Galgano *et al.,* 2025). It could be due to chromosomal mutations or the horizontal acquisition of resistant genes via mobile genetic elements such as plasmids, transposons, integrons, or bacteriophages (Davies & Davies, 2010). HGT is of epidemiological importance because it allows the dissemination of resistance determinants among bacterial species, genera, and ecological niches, including human-animal pathogen transfer and vice versa (Van Boeckel *etal.,*2019).

Classification of Antimicrobials Commonly Used in Veterinary Medicine

Antimicrobials are primarily classified by the type of microorganism they target, their specific mechanism of action, their chemical structure, their spectrum of activity, and whether they kill or merely inhibit microbial growth. The major classes used in livestock production are beta-lactams (penicillin, cephalosporins, carbapenems), tetracyclines, aminoglycosides, sulphonamides, macrolides, fluoroquinolones, lincosamides, and polymixins (Guardabassi *et al.,* 2008). The various classes target specific bacterial functions, such as cell wall synthesis, protein synthesis, DNA replication, and membrane integrity (Baran *et al.,* 2023).

Antimicrobials have been classified into three categories: "important", "highly important" and "critically important" based on veterinary stewardship, due to public health concerns about the risk of resistance transfer across the human-animal interface resulting from their use in food-producing animals (WHO, 2019). Critically important (CIAs) include third-generation and fourth-generation fluoroquinolones, colistin, and cephalosporins, which are usually considered a last resort for the treatment of serious infections in humans (Rhouma *et al.,* 2022).

In Nigeria, the widespread over-the-counter availability of affordable, broad-spectrum antibiotics, particularly tetracyclines, penicillins, and sulphonamides, without a veterinary prescription, drives their heavy use. These factors reflect a broader trend observed across the African small-ruminant livestock sector (Abate & Birhanu, 2025). Studies have documented the procurement of antimicrobials from veterinary drug vendors, general markets, and pharmacies, often without professional advice and sometimes using human-licensed products at sub-therapeutic doses in animals (Al-Mustapha *et al.,* 2020). Such practices not only drive local resistance but may also contribute to the global AMR burden through international trade in livestock products.

Clinically, a distinction must be made between therapeutic, prophylactic, and anaphylactic uses of antimicrobials in the treatment of diagnosed disease and in prevention, as well as subtherapeutic use as growth promoters. This use persists in Low- and Middle-Income Countries (LMICs), including Nigeria, thereby creating sustained, low-level selective pressure that favours the emergence of resistant strains.

Global Burden of Antimicrobial Resistance in Animal Health Systems

The global burden of AMR in animal health systems is substantial and escalating. The estimated global antimicrobial consumption in livestock was 63,151 tonnes in 2010 and is projected to increase by 67% by 2030, driven primarily by expanding demand for animal protein in Asia, Africa, and Latin America (Van Boeckel *et al.,* 2015). Critically, this trajectory of antimicrobial use directly correlates with the rising prevalence of antimicrobial resistance in livestock pathogens worldwide.

In food-producing animals, mastitis pathogens are of high importance in AMR surveillance, not only because of their direct clinical and economic impact but also because they can act as reservoirs of resistance genes that may be transferred to pathogens of human importance (Kazemzadeh *et al.,* 2025). An example is the recovery of resistant *Staphylococcus aureus*, including MRSA, from mastitis cases in cattle, sheep, and goats in Europe, North America, and increasingly in Africa, with evidence of livestock-to-human transmission in farm settings (Vanderhaeghen *et al.*,2010).

The global antimicrobial resistance and use surveillance system (GLASS), established by the WHO in 2015, has progressively expanded its data collection to include the veterinary and agricultural sectors (Ajulo & Awosile, 2024). Data from the tripartite AMR monitoring framework, encompassing the WHO, the Food and Agriculture Organisation (FAO), and the World Organisation for Animal Health (WOAH/OIE), documented increasing rates of resistance to fluoroquinolones, tetracyclines, and beta-lactams in zoonotic pathogens such as *Salmonella* spp., *Campylobacter* spp., and *E. coli* isolated from livestock across multiple regions (WHO, 2021).

Importance of Mastitis in Small Ruminant Production Systems

Mastitis is one of the most economically significant diseases of the mammary gland in dairy small ruminants worldwide, with economic losses arising from multiple pathways: direct losses include milk yield reduction (estimated at 10–40 % in clinical cases), premature culling, treatment costs, milk discarding during treatment, and mortality from severe infections (Mumba *et al.,* 2026). Indirect losses include reduced reproductive performance, reduced kidding and lambing rates, and impaired growth in suckling offspring (Contreras & Rodríguez, 2011).

In Nigeria, where many small ruminants are raised under extensive systems primarily for meat and secondary milk production, the economic significance of mastitis extends beyond milk yield to reproductive efficiency and live weight gain (Adamu *et al.,* 2020). Sheep and goats serve as critical assets for rural households, functioning simultaneously as walking food banks, financial reserves, and cultural currency (Oluwatayo & Oluwatayo, 2012). Any disease that reduces productivity, increases costs, or accelerates culling directly threatens household income and food security (Patil, 2024).

Conceptual Clarifications and Key Definitions

Small Ruminants: Sheep and Goats in the Nigerian Context

Small ruminants are an important livelihood asset for rural Nigerian households, which account for 70–80% of households that own one or more forms of small livestock (Wudil *et al.,* 2025). The majority of them are kept for subsistence and financial security, social capital, and cultural expression (Oluwatayo & Oluwatayo, 2012). When compared with large ruminants such as cattle, they are accessible to economically marginalised households due to their lower purchase costs, smaller feed requirements, and more manageable husbandry demands (Busari *et al.,* 2025).

Nigeria has the largest small ruminant population in Africa (Ijoma *et al.,* 2025). According to the FAO 2021, Nigeria harbours approximately 43.4 million goats and 47.8 million sheep, representing a significant proportion of sub-Saharan Africa's total small ruminant inventory. These animals are distributed across all agro-ecological zones, from the arid north to the humid south, reflecting their ecological adaptability (Ijoma *et al.,* 2025). [48]. In northern Nigeria, especially in states like Sokoto, Kano, Zamfara, and Katsina, small ruminants are deeply integrated into the livelihoods of traditional Fulani pastoralists and settled farmers, often serving as a primary or secondary source of household income (Higazi, 2022). For instance, the Red Sokoto goat and the Yankasa and Uda sheep breeds are particularly prevalent and valued for their meat quality, reproductive performance, and adaptation to semi-arid environments (Lawal-Adebowale, 2012).

Knowledge and Perception of Small Ruminant Farmers on the One Health Context

Small Ruminant Production Systems in Nigeria

Small ruminant production in Nigeria is generally classified into extensive, semi-intensive, and intensive management systems, each influencing animal productivity, health, and antimicrobial use differently (Mustapha *et al.,* 2024). The extensive system, comprising pastoral and agropastoral practices, predominates in the Sudan and Sahel savanna regions of northern Nigeria (Amole *et al.,* 2022). Animals graze freely over large areas with minimal supplementary feeding, housing, and veterinary care (Ayantunde & Amole, 2016). Its major advantage is its low production cost, due to reliance on natural pasture and limited infrastructure requirements. However, unrestricted herd movement, particularly during transhumance, facilitates the spread of infectious diseases and antimicrobial-resistant pathogens, while low productivity and poor access to veterinary services remain significant constraints (Ghali-Mohammed *et al.,* 2025).

The semi-intensive system is commonly practised in the Guinea savanna and forest zones, especially in the Middle Belt and southwestern regions, where land availability restricts open grazing. Animals are housed at night, grazed or tethered during the day, and provided with supplementary feed. This system offers improved nutrition, disease monitoring, reproductive performance, and veterinary care compared with extensive production. Nevertheless, it entails greater labour, housing, and feeding costs, and increased animal handling and veterinary interventions may lead to higher antimicrobial use if not properly regulated.

Intensive production systems, though less common in Nigeria, are increasingly adopted by peri-urban and commercial farmers to meet the growing demand for meat and milk (McKnight & Ibeagha-Awemu, 2019). These systems enhance productivity through controlled feeding, breeding, and health management, as well as improved biosecurity and record-keeping. However, high stocking densities, stress-related immunosuppression, and increased dependence on antimicrobials elevate the risk of disease outbreaks and antimicrobial resistance. Consequently, sustainable management and prudent antimicrobial use are essential across all production systems to ensure animal health and productivity.

The distribution of ruminant livestock population by ecological zones of Nigeria, as reported by the Federal Department of Livestock and Pest Control Services (FDLPCS), shows that 71.50 % sheep and 81.30 % goats are found in the Savannah ecological zone, with an estimated population of sheep and goats in Nigeria of 127 million sheep and 147 million goats (Yusuf *et al.,* 2018). Ruminants play a significant role in livestock production, especially in Nigeria, where rural dwellers rear them for meat, milk, skin, and wool (Yusuf *et al.,* 2018). Small ruminant production among the Hausa is described as a compound system in which small herds of goats are kept in their compounds and fed silage during the rainy season, and sheep are also allowed to graze with cattle (Yusuf *et al.,* 2018).

Socio-Economic Importance of Sheep and Goats to Rural Livelihoods

Small ruminants are a fundamental livelihood asset for rural Nigerian households, with about 70–80% of households rearing one or more small livestock species, particularly small ruminants (Umunna *et al.,* 2014). The purposes of rearing include financial security, social capital, and cultural expression, as they are accessible to economically marginalised households due to their lower purchase costs, smaller feed requirements, and more manageable husbandry demands compared to large ruminants (Adamu *et al.,* 2020). The cultural and ceremonial significance of small ruminants is profound. Sheep and goats are integral to Islamic religious observances, especially the annual Eid al-Adha (Sallah) festival, when demand rises, and prices for well-conditioned animals surge (Ibrahim *et al.,*2019). This increases the use of antimicrobials among farmers as growth promoters and feed additives.

Health Management Practices in Small Ruminant Farming

Availability of resources, knowledge, cultural norms, and access to veterinary services affect health management practices among Nigerian farmers (Kolawole *et al.,* 2007). Routine vaccination, deworming, hygienic milking, and nutrient supplementation are carried out in semi-intensive and extensive systems where access to veterinary care is limited (Pasteur *et al.,* 2024).

In recent times, research has repeatedly shown that traditional or empirical approaches to disease management are used by Nigeria's small ruminant farmers (Adegoke & Abioye, 2016). In the absence of official veterinary consultation, regional herbal medicines, thermal therapies, local spiritual interventions, and counsel from other farmers are used (Enwelu *et al.,* 2015). Antimicrobials are often purchased without a prescription from veterinary pharmacies and most drugs are often purchased from the open markets when pharmacological intervention is needed, and then administered at self-determined doses and durations based on past experience or advice from drug sellers rather than expert advice. These practices have significant implications for AMR due to selective pressure (Caneschi *et al.,* 2023).

Challenges in Veterinary Service Delivery for Small Ruminant Farmers

The provision of veterinary care for small ruminant farmers in Nigeria faces complex challenges (Nwobodo *et al.,* 2022). The ratio of veterinarians to livestock units in Nigeria is estimated at 1:50,000 at the structural level, significantly lower than the FAO-recommended ratio of 1:5,000. Due to the concentration of qualified veterinarians in urban areas, rural areas, where most small ruminant production takes place, are disproportionately underserved; therefore, the use of ethnoveterinary methods is warranted (Enwelu *et al.,* 2015).

Extension officer-to-farmer ratios are extremely unfavourable, and the frequency of farm visits is insufficient to adequately influence farmer knowledge or behaviour (Antwi-Agyei & Stringer, 2021). Where extension services do function, the content often focuses on major livestock species (cattle, poultry) at the expense of small ruminants (Pousga *et al.,* 2022). The extension delivery service has been severely degraded by decades of structural adjustment, resource cuts, and institutional neglect. This creates a gap between farmers' technical and veterinary knowledge and practices (Pousga *et al.,* 2022).

The lack of adequate regulatory enforcement of veterinary drug legislation plays a critical role in the use of over-the-counter products and the availability of counterfeit and substandard veterinary medicine, which, without a strict enforcement mechanism, will not influence farmers' behaviour (Smith, 2013).

Mastitis in Small Ruminants

Definition and Classification of Mastitis

Milk is one of the most complete foods (Górska-Warsewicz *et al.,* 2019). Goat milk is renowned for its superior quality and digestibility, which are comparable to those of human milk (ALKaisy *et al.,* 2023). Goat milk is a vital source of income and sustenance for rural and peri-urban inhabitants in developing nations (Khowa *et al.,* 2023). However, mastitis is the most economically significant illness in the dairy sector due to its effect on milk production (Ji *et al.,* 2023). Sheep milk is also an important raw material for producing high-quality cheeses and yoghurts in Mediterranean countries (Olechnowicz & Jaśkowski, 2014).

Mastitis is any inflammation of the mammary gland or udder, irrespective of its evolution or origin and severity (Cheng & Han, 2020). The term mastitis was coined from the Greek words: mastos (for breast) and itis (for inflammation). Mastitis, especially the subclinical form, can be a significant problem in intensively managed sheep and goat flocks for meat or milk production (Olechnowicz & Jaśkowski, 2014). It is a disease complex characterised by inflammation of the mammary gland tissue due to mechanical damage or infection (Khasapane *et al.,* 2023). Most cases in small ruminants are caused by the interplay among the host, pathogen, and environment (Kimeli *et al.,* 2025). Most intramammary infections (IMIs) result from bacterial dissemination from cutaneous to mammary sites during milking, triggering the host immune response, which initiates inflammation and helps heal the injured gland by eliminating the irritant (T. Mwenge Kahinda, C., 2022).

Mastitis can be broadly classified as clinical or subclinical, with the difference being the presence or absence of external inflammatory signs and the occurrence of specific pathogens isolated from the milk (Ji *et al.,* 2023). Clinical mastitis is not as common as the subclinical cases, and it is characterised by pain, redness and reduced milk production in quality and quantity from the affected udder and may involve systemic signs in severe cases (Tommasoni *et al.,*2023). There may also be abnormal cells in the milk, appearing as clots, strings, or flakes, and they may appear watery (Cheng & Han, 2020). In Subclinical mastitis, the milk and udder may appear normal and can only be detected by measuring somatic cell count (SCC) with the California mastitis test (CMT).

In Africa, subclinical mastitis in small ruminants significantly affects the production and productivity of dairy goats and sheep, as it often lacks clinical signs detectable by clinicians or farmers (Adelowo *et al.,* 2022). Lactating ewes/does with subclinical mastitis do not show any clinical symptoms and produce apparently normal milk for a long period; this is only revealed after indirect tests, such as CMT, are performed and the sample is cultured for bacteriological examination, which then becomes positive for mastitis (Hayle *et al.,*2020).

Risk Factors Associated with Mastitis in Small Ruminants

Mastitis in small ruminants is a multifactorial disease influenced by animal, environmental, and management-related factors. Poor milking hygiene, contaminated housing environments, inadequate nutrition, overcrowding, teat injuries, and poor udder conformation are among the major risk factors that predispose sheep and goats to intramammary infections (Brito *et al.,* 2025). The risk is further increased in intensive production systems where animals are kept in close proximity, facilitating the transmission of mastitis-causing pathogens such as *S. aureus*, coagulase-negative staphylococci, and various environmental bacteria. In addition, lactation stage, parity, age, and previous history of mastitis have been identified as important host-related risk factors that influence disease occurrence and severity (Cheng & Han, 2020).

The management of mastitis often relies heavily on antimicrobial therapy. However, the frequent, sometimes indiscriminate, use of antibiotics in livestock production has become a significant concern (Saeed *et al.,* 2024). For instance, Antibiotics are commonly used to treat and prevent mastitis and other bacterial infections, but excessive or inappropriate use exerts selective pressure on bacterial populations, promoting the emergence and spread of antimicrobial-resistant strains (Adesokan *et al.,* 2015). As antibiotic exposure increases, susceptible bacteria are eliminated while resistant organisms survive, multiply, and disseminate within animal populations and the environment. This phenomenon has important public health implications because resistant bacteria and resistance genes can be transmitted between animals, humans, and the environment through direct contact, food products, and environmental contamination (Woolhouse *et al.,* 2015).

The development of antimicrobial resistance in mastitis pathogens complicates treatment outcomes by reducing the effectiveness of commonly used drugs, resulting in prolonged infections, increased morbidity, and occasional mortality (Kazemzadeh *et al.,* 2025). Consequently, farmers incur higher treatment costs due to repeated therapeutic interventions and the need for more expensive alternative antimicrobials. Persistent mastitis also leads to reduced milk yield, poor milk quality, decreased reproductive performance, and overall economic losses in small-ruminant entlose spaceerprises (Borş *et al.,* 2024). Therefore, effective mastitis control requires a combination of good husbandry practices, improved hygiene, regular health monitoring, prudent antimicrobial use, and antimicrobial stewardship programs to preserve the efficacy of available antibiotics for both animal and human health (Adesokan *et al.,* 2015; Woolhouse *et al.,* 2015).

Mastitis-Causing Microorganisms

Bacterial Agents Commonly Associated with Mastitis

Several pathogens can cause mastitis, but *Staphylococcus* spp. are the most frequently diagnosed causal microorganisms of intra-mammary infections in goats and sheep (Polveiro *et al.,* 2022). Bacterial agents associated with mastitis include *Streptococcus* spp., *Enterococcus* spp., *E. coli*, *Pasteurella* spp., *Mycoplasma* spp., and other viral and fungal agents (Hayle *et al.,* 2020).

In sheep, a number of bacterial pathogens associated with mastitis, including *S. aureus*, *Mannheimia* spp., *Streptococcus* spp. and non-aureus *staphylococci* (T. Mwenge Kahinda, C, 2022). *S. aureus* is a zoonotic Gram-positive organism that presents as a commensal in mammals as well as an opportunistic pathogen (Mørk *et al.,* 2007). It is the most common cause of clinical mastitis in sheep, accounting for about 80 % of cases in milking ewes and 40 % in suckling lambs (Mørk *et al.,* 2007). Mastitis caused by *S. aureus* is usually difficult to treat or cure and is highly contagious; as such, the affected animals are culled or milked last to limit the spread of infection within the flock (Kerro & Vidlund, 2024). *M. haemolytica* is a non-motile, spore-forming, Gram-negative, bipolar rod bacterium predilected in the nasal and nasopharyngeal cavities of healthy animals (Shi *et al.,* 2025). It causes mastitis in the wool and meat sheep industry (Omaleki *et al.,* 2010). It is more important than *S. aureus*-induced mastitis because it can be transmitted to suckling lambs of affected ewes, leading to pneumonias (Fotou *et al.,* 2026).

Streptococcus spp. are zoonotic, non-spore-forming, anaerobic, Gram-positive bacteria responsible for sporadic outbreaks of mastitis in flocks of sheep and goats (Las Heras *et al.,* 2002). Incidence of mastitis caused by this organism has been associated with poor hygiene during milking and is common in animals with a milking machine (Mramba *et al.,* 2024). Examples of commonly isolated species are *S. agalactiae, S. uberis, S. dysagalactiae,* and *S. equi subsp. Zooepidemicus* (Cito *et al.,* 2025).

In Goats, bacteria associated with goat mastitis include *Staphylococcus* spp.; *Streptococcus* spp.; *Bacillus* spp.; *Listeria* spp.; *Corynebacterium* spp.; *Pseudomonas* spp.; *Mycoplasma* spp.; *Manhemia haemolytica*; *Clostridium perfringens* and *Escherichia coli.* The most common being *S. aureus*, responsible for subclinical to gangrenous mastitis and high pathogenicity, which are difficult to treat, and the affected goat remains a reservoir host for the spread of infection (Smith *et al.,* 2026).

Economic and Productivity Impacts of Mastitis

Mastitis is a very serious disease that affects not only meat and milk production but also the well-being of small ruminants and even human health. The importance of mastitis in small ruminants can be gathered from three perspectives (Ezzat Alnakip *et al.,* 2014)., which are: economic, including mortality of animals, treatment costs, reduced quantity and quality of milk; hygienic, the risk of infection or poisoning of consumers by consuming infected milk, and legal (definitions of bacteriological milk quality) (Olechnowicz & Jaśkowski, 2014).

In Nigeria, the quantity of milk produced is inadequate to meet the need of the population as a result of mastitis which leads to high loss ranging from reduced milk production due to damage to the mammary tissues, increased cost for veterinary care, culling of infected animals and replacement, risk of antimicrobial residue in milk leads to discarding of milk and the period of lactation is also affected (Ji *et al.,* 2023). Antibacterial residues from food-animal origin have been implicated in contributing to antibacterial resistance, making it difficult to manage clinical diseases (Pal *et al.,* 2025).

The economic impact of mastitis in small ruminants is perceived from economic, legal, and hygienic points of view, with effects on lamb growth, ewe mortality, treatment costs, and reduced milk production and prices, which account for about $35 billion in annual losses worldwide (Hayle *et al.,* 2020).

Public *Health Implications of Mastitis-Associated Pathogens*

Staphylococcus colonisation has been ascribed to be dependent on human host factors, with its exposure raising public health concerns similar to the Human Immunodeficiency Virus (HIV) burden, especially in Nigeria (Ogunleye *et al.,* 2025). The microbial isolation of these organisms is of public health importance because they can cause food poisoning upon ingestion of contaminated milk or its products without pasteurisation, particularly the enterotoxin-producing strains of *Staphylococcus* (Ji *et al.,* 2023). Most organisms become resistant to antimicrobials due to sub-therapeutic treatment by farmers (Manyi-Loh *et al.,* 2018). The use of antimicrobial agents for the treatment of mastitis caused by bacteria poses a risk of antibiotic resistance in bacteria, with a resultant effect on human health from the consumption of raw sheep or goat dairy products (Kazemzadeh *et al.,* 2025).

Risk factors for mastitis occurrence in small ruminants

Poor hygiene

Poor hygiene is one of the most important risk factors associated with mastitis in small ruminants (Brito *et al.,* 2025). Unsanitary housing conditions, accumulation of manure and bedding materials, contaminated water sources, and inadequate udder hygiene create favourable conditions for the proliferation and transmission of mastitis-causing pathogens (Yu *et al.,*2025). Among these pathogens, *S. aureus* remains one of the most frequently isolated bacteria in cases of caprine and ovine mastitis and is recognised as a major cause of both clinical and subclinical intramammary infections (Exel *et al.,* 2023). Although *S. aureus* is traditionally considered a contagious pathogen transmitted during milking, studies have demonstrated that it can colonise extramammary body sites, including the nares, skin, and udder surface, which may serve as reservoirs for intramammary infections (Exel *et al.,* 2023).

Poor hygienic practices during milking further increase the risk of mastitis transmission within a herd. Failure to wash and disinfect hands, udders, and milking equipment before and after milking can facilitate the transfer of pathogens from infected to healthy animals (Desisa & Mitiku, 2025).

Contaminated teat cups, improperly maintained milking machines, and inadequate sanitation of the milking environment have been implicated in the spread of *S. aureus* mastitis among dairy goats. Recent evidence from a high-mortality outbreak of caprine mastitis identified poor milking hygiene and milking equipment dysfunction as major contributors to the rapid dissemination of *S. aureus* within affected herds (Smith *et al.,* 2036).

The consequences of poor hygiene extend beyond increased disease prevalence. Intramammary infections caused by environmental contamination can lead to elevated bacterial counts in milk, reduced milk yield and quality, increased veterinary costs, and higher culling rates (Piepers *et al.,* 2009). Furthermore, persistent infections may require repeated antimicrobial treatments, thereby increasing the risk of antimicrobial resistance development.

Milking Practices

Poor milking hygiene is a primary risk factor for the transmission of mastitis in dairy small-ruminant herds (Bergonier *et al.,* 2003). The absence of teat pre-dipping and post-dipping with antiseptic solutions, milking from infected to healthy animals without teat disinfection, and the use of shared milking cloths facilitate the direct transfer of mastitis-causing pathogens from infected to uninfected quarters, as well as a lack of proper hand washing hygiene, especially in Africa and Nigeria, where awareness is inadequate or limited (Bergonier *et al.,* 2003; Garba, 2021).

Housing Conditions

Overcrowded, poorly ventilated, and inadequately bedded housing promotes the growth of environmental pathogens, such as Gram-negative organisms like *Klebsiella* and *Pseudomonas* spp. (Onmek *et al.,* 2020). Udder trauma from rough surfaces, wet and soiled bedding, and environmental conditions that favour pathogen growth can increase the risk of bacterial colonisation of the teat, leading to infection (Contreras & Rodríguez, 2011).

Antimicrobial Use in Small Ruminant Farming

Commonly Used Antimicrobials in Mastitis Treatment

The major antibacterial used targets Gram-positive organisms, particularly *Staphylococcus* and *Streptococcus* (Hayle *et al.,* 2020). Other factors to consider include the spectrum of activity of the drug of choice, the safety of the antibacterial agents, and the cost of the drug (Gajic *et al.,* 2025). Among the commonly used agents are intramammary ampicillin-dicloxacillin and intramuscular amoxicillin-clavulanic acid, which are not highly effective when used as sole treatments (McDougall *et al.,* 2019).

About 12 varieties of antimicrobials are used on different dairy farms for the treatment of mastitis, among which are ciprofloxacin, amoxycillin, ceftriaxone, gentamicin, penicillin, streptomycin, tetracycline, cloxacillin, sulfamethoxazole-trimethoprim, neomycin, and kanamycin, which were reported to be minimal compared to other agents (Roca *et al.,* 2015).

Patterns of Antimicrobial Use in Livestock in Nigeria

The quantities of the different antibiotics sold mainly for use in livestock including cattle, sheep and goats over the three years were obtained from records and expressed as units of frequencies of sales with units of 11 different antibiotics which belong to six antimicrobial classes were sold over the three years of study in south-west Nigeria, tetracyclines (33.6%) were the most frequently sold antimicrobials, then fluoroquinolones (26.5%), beta-lactams/aminoglycosides (20.4%) and macrolides (15.1%). Others were furatadone (2.3%) and chloramphenicol (2.1%) (Adesokan *et al.,* 2015).

Sources of Antimicrobials (Veterinary Prescription vs. Informal Markets)

Antibiotics are more frequently obtained from informal sources (33.3%) than from formal sources, such as veterinary pharmacists (22.2%). The majority of farmers rely on advice from livestock technicians (32%), veterinarians (26%), and livestock veterinary auxiliaries (20%), while 28% rely on personal experience (Bodombossou *et al.,* 2025).

Antimicrobial Resistance in Mastitis-Causing Microbes

Evidence of Antimicrobial Resistance in Mastitis Pathogens

AMR among mastitis-causing bacteria in small ruminants has been reported at alarming levels across multiple geographic regions, including sub-Saharan Africa. *Staphylococcus aureus* remains one of the most commonly isolated mastitis pathogens in dairy sheep and goats worldwide, and its resistance patterns are of concern due to its pathogenicity, biofilm-forming capacity, and role as a reservoir for transferable resistance determinants (Gelasakis *et al.,* 2015).

Streptococcal resistance to macrolides, tetracyclines, and lincosamides is increasingly documented and is associated with the acquisition of *erm* genes and *tet* determinants via mobile genetic elements (Kaczorek *et al.,* 2017).

Small ruminants develop mastitis, which is characterised by changes in the physical, chemical, and microbial characteristics of the milk as well as pathological lesions in the glandular tissue with detection of the three most common mastitis-causing pathogens (*Staphylococcus aureus*, *Escherichia coli*, and *Streptococcus* spp. in a study carried out on Shami goats (Ebissy *et al.,*2024). In a comparable study from China, found that all *S. aureus* isolates from caprine mastitis were penicillin-resistant (85.2%), demonstrating multidrug resistance (Shi *et al.,* 2025). These findings are consistent with African data reviewed by some researchers (Abebe *et al.,* 2024; Machado da Silva *et al.,* 2025), who noted a concerning upward trend in MRSA prevalence in livestock across continents.

Public Health and Animal Health Implications of Resistant Strains

The persistence of resistant strains in udder infections leads to treatment failure, ineffective therapy, prolonged infection duration, increased pathogen shedding, and further antimicrobial use that amplifies the resistance loop (Contreras & Rodríguez, 2011). The financial implications of treatment affect smallholder farmers, who may increase the dose, switch antimicrobials indiscriminately, or abandon treatment altogether.

Zoonotic Risks Associated With Resistant Mastitis Pathogens

Zoonotic transmission of mastitis pathogens and their associated resistance biomarkers occur through several pathways, including consumption of raw or inadequately pasteurised milk and dairy products, direct contact at the farmer-mastitic animal interface, and environmental contamination of water and soil with mastitic milk or animal waste.

The best-characterised zoonotic mastitis pathogen, MRSA of livestock origin (LA-MRSA), *S. aureus*, particularly LA-MRSA clonal complex 398 (CC398), originally described in European pig production, has been isolated from cattle, sheep, and goats with mastitis. Farmers, veterinarians, and slaughterhouse workers with frequent animal contact have also been reported, which underscores the need for community and occupational concern (Vanderhaeghen *et al.*, 2010; Cuny *et al.*, 2015). An integrated surveillance spanning both sectors is critical for accurately characterising zoonotic AMR risks.

Farmers' Knowledge of Antimicrobial Resistance

Concept of Knowledge in AMR studies

Antimicrobial resistance has been attributed to the inappropriate use of antimicrobials in animal production, leading to hazardous effects on environmental, animal, and human health. Antibiotics are used by farm owners and workers and obtained from private pharmacies without veterinarians' or health care professionals' approval (Kallu *et al.*, 2024). A study also conducted in Turkey found that farmers lacked adequate knowledge of antibiotics and their uses, with about 38% reporting no side effects from their use. The majority considered antibiotics to be analgesic and antipyretic drugs (Adedeji, 2016).

Awareness of Antimicrobials and Resistance among Livestock Farmers

The ability to identify antimicrobials, understand their function, and appreciate the consequences of their misuse is minimal among livestock farmers in Nigeria and other LMICs. Several studies, including the current survey, reported that the majority of small ruminant farmers demonstrate basic familiarity with antimicrobials, meaning they can name specific products and identify situations in which they are commonly used. However, do not understand the mode of action, the biological basis of resistance, or the distinction between bacterial, viral, and parasitic infections (Wakawa, A).

Factors Influencing Farmers' Knowledge (Education, Extension Services, Experience)

Education level is consistently identified as a positive predictor of antimicrobial knowledge in surveys of livestock farmers. As related by Oloso *et al.*, they noted that farmers with secondary or postsecondary education were significantly more likely to report awareness of AMR concepts and to seek veterinary advice before administering antimicrobials than farmers with no formal education (Oloso *et al.*, 2022). This corroborates the survey results of the current study. Years of farming experience and the number of disease management episodes are double-edged factors. Experienced farmers usually have practical knowledge of disease recognition and basic management, but they may also have developed entrenched habits and heuristics from prior successful antimicrobial use that are difficult to change and resistant to abandoning suboptimal practices. The Nigerian extension system is severely under-resourced, and the quality and relevance of extension communications on AMR are inconsistent. Even where extension services function, they often focus primarily on livestock production (feeding, breeding, marketing, etc.) rather than on health management, leaving farmers without accurate information about antimicrobial use and resistance (Fasina, F.).

Gaps in Knowledge Reported in Previous Studies

Knowledge of withdrawal periods, the interval between the last antimicrobial administration and safe use of milk or slaughter, is frequently inadequate or lacking among farmers. Studies in Nigeria have documented that the majority of small ruminant farmers either do not know Swhat a withdrawal period is or do not adhere to the recommended intervals, leading to antimicrobial residues entering the food chain (wakawa, A.). Also, a lack of understanding of the mechanisms of action of different antimicrobial classes and the inappropriate use of antibiotics to treat viral infections. Farmers routinely administer antimicrobials in response to fever, coughing, or diarrhoea without proper diagnosis, contributing to unnecessary antimicrobial use and the accelerated selection of resistance.

Evidence Linking Farmers' Practices to Microbial Resistance Patterns

Antimicrobial use and resistance are associated with the persistence of resistance genes even in the absence of continued selection pressure, as well as with the flow of animals and pathogens between farms. Mobile genetic elements carrying multiple resistance determinants can maintain resistance to antimicrobials not currently in use on a given farm through co-selection with another antimicrobial in use (Van Boeckel *et al.*, 2019).

Role of Farmer Behaviour in the Emergence and Spread of AMR

The use of antimicrobials for prophylactic and as a 'first response' to any sign of illness, sharing of antimicrobials between neighbouring farmers, and the stockpiling of antimicrobials purchased in bulk from markets have all been documented as common practices among Nigerian small ruminant farmers (Karvellas *et al.*, 2014). Factors such as individual and cultural beliefs, economic considerations, social norms and availability of antimicrobial agents are implicated. This is in line with the findings of this current study.

Integrated Human–Animal–Environment Perspective (One Health Approach)

The surge in mastitis prevalence, widespread antimicrobial use, and consumption of raw small ruminant milk in Nigerian communities creates a multifaceted condition that is not adequately captured by either veterinary or human health surveillance systems. Integrated surveillance spanning both sectors is critical for accurately characterising zoonotic AMR risks from a One Health perspective as shown in Figure 1.

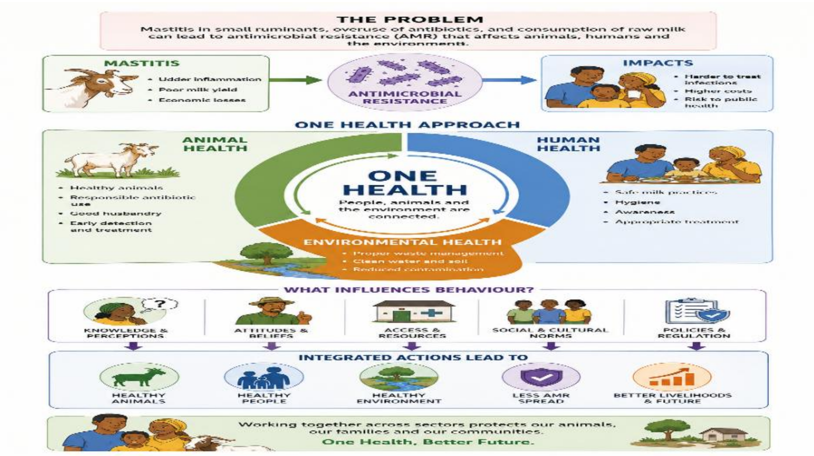

Figure 1: Illustration showing the One-Health Approach to AMR and Mastitis

Empirical Review of Related Studies

Studies on Mastitis Prevalence in Small Ruminants

In a cross-sectional study conducted in Ethiopia from October 2017 to April 2018 by Hayle *et al*., the prevalence of mastitis in the clinical form was <5%, while the subclinical form accounted for 37.6% in small ruminants. While the clinical forms are characterised by evidence of udder appearance and milk changes, subclinical forms can be detected by conducting indirect tests such as CMT, White Side Test (WST), SCC, and laboratory pathogen Isolation. Coagulase-negative *S. aureus*, which leaks through the udder during milking and can then be transferred to other animals through equipment, is one of the causative agents. Other causative agents include *Streptococcus* spp., *Enterococcus* spp., *E. coli*, *Pasteurella* spp., and viral and fungal agents (Hayle *et al*., 2020).

Studies on AMR in Livestock in Nigeria and Similar Settings

In the Nigerian extension system, it is severely under-resourced, and the quality and relevance of extension communications on AMR are inconsistent. Where extension services operate, they often focus on livestock production (feeding, breeding, marketing) rather than on health management; hence, farmers have little or inaccurate information about proper antimicrobial use and AMR.

A few studies focused on mastitis management in small ruminants in northern states, such as Kano State (Wudil *et al.*, 2025; Yerima *et al.*, 2021). He found that 78% of farmers could identify the clinical signs of mastitis, but only 23% had ever submitted milk samples for laboratory diagnosis. Antimicrobial selection was based on drug vendor recommendation (54%), prior experience (32%), or peer advice (14%), with veterinary prescription guiding treatment in fewer than 10% of cases.

Antibiotics are more frequently obtained from informal sources (33.3%) than from formal sources, such as veterinary pharmacists (22.2%). The majority of farmers rely on advice from livestock technicians (32%), veterinarians (26%), livestock veterinary auxiliaries (20%), and 28% rely on personal experience (Bodombossou *et al.*, 2025). These patterns are related to the findings in this project.

Methodological Gaps Identified in the Existing Literature

Reliance on cross-sectional studies for knowledge, attitude, and perception (KAP) surveys and prevalence studies is a critical gap in small ruminant production. This method can identify the association between knowledge and practice regarding resistance, but not the resistance profile, which other methods can track. Most studies on mastitis in small ruminants are reported from the northern part of the country, such as Sokoto and Kano, which do not provide a full representation of practices and pathogen ecology in other parts of the country (Shittu *et al.*, 2008). Cultural tools across various geographic locations need to be in place to adequately assess farmers' knowledge and perceptions of AMR in small ruminants and ensure accuracy.

The paucity of integrated studies that simultaneously assess farmer KAP, antimicrobial use practices, and pathogen resistance profiles, as in this study's design, whereas most studies address these in isolation, limiting the ability to test likely causal chains. Raboloko *et al.* also conducted a KAP study on antimicrobial use among livestock farmers in LMICs, which reveals several recurring knowledge gaps, including farmers' underestimation of the human health risks associated with resistant pathogens in livestock, and the potential for AMR transfer from animals to humans through the food chain or direct contact (Raboloko *et al.*, 2026). Also, there is limited molecular characterisation of resistance, as most studies focus on phenotypic susceptibility testing, which affects the documentation of resistance genes and patterns in global databases.

MATERIALS AND METHODS

Behavioural Theories Relevant to Knowledge and Perception

Several behavioural theories provide useful conceptual means for understanding and predicting farmer AMR-related behaviour. The Health Belief Model (HBM), originally developed by Rosenstock et al., for human preventive health behaviour, claims that an individual's likelihood of adopting a health-promoting behaviour is determined by their perceived susceptibility to a health threat, severity of the threat, benefits of the action, and barriers associated with taking it (Rosenstock, 1974) as shown in Figure 2.

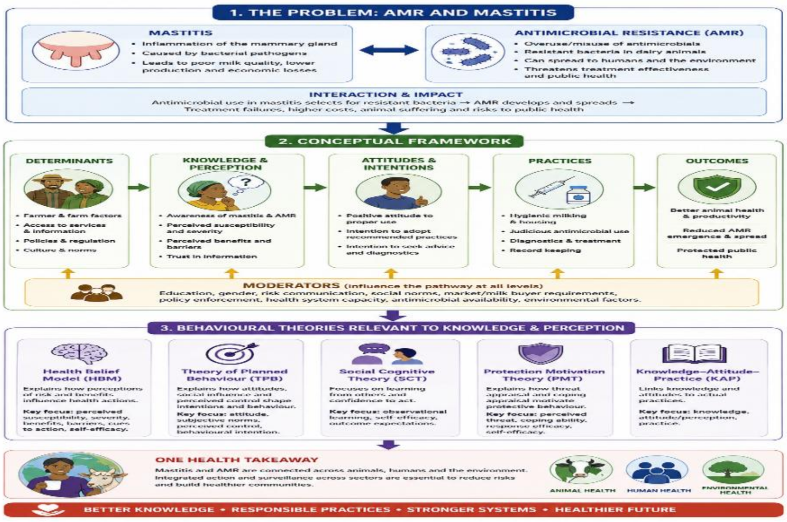

Figure 2: Behavioural Theories Relating to AMR and Mastitis

Farmers' Knowledge and Perception

Social norms and peer practices shape farmers' perceptions of the appropriate use of antimicrobials and their efficacy, which are associated with planned behaviour and social learning theories. This model encompasses farmers' factual knowledge of mastitis aetiology, antimicrobials, and resistance, as well as their attitudes toward AMR risk, perceived severity of mastitis, and perceived benefits and barriers associated with the adoption of recommended disease prevention and treatment practices. It also considers farmers' confidence in identifying mastitis, their understanding of prudent antimicrobial use, and their willingness to seek veterinary advice when managing animal health problems. These perceptions influence decision-making regarding antimicrobial use, adherence to treatment guidelines, and the acceptance of alternative mastitis control measures, ultimately affecting the emergence and spread of antimicrobial resistance within small ruminant production systems.

Antimicrobial Use Practices

Antimicrobial use practices include the specific patterns and decisions around antimicrobial selection, source of procurement, dosing, duration, adherence to withdrawal periods, and frequency of use. This is then influenced directly by farmers' knowledge and perception in that higher awareness and more accurate beliefs are associated with more appropriate use practices, but is also shaped independently by structural determinants such as the availability of veterinary services, regulatory enforcement, and the economic context of production.

Prevalence of Mastitis-Causing Resistant Microbes

Prevalence of clinical mastitis in small ruminants is usually below 5%, while subclinical mastitis ranges from 9 to 50%, and on average, 5-30% prevalence in small ruminants. This is related to microbiological outcomes and is associated with the effect of the frequent, indiscriminate use of antimicrobials on pathogens, leading to a higher rate of resistant pathogens responsible for mastitis. If there is high resistance, it triggers streatment failure, and if farmers are aware, it may modify their behaviour and knowledge.

CONCLUSION

Farmers especially in LMICs have limited knowledge on AMR and often practice irrational use of antibiotic for management of diseases. Some practices, such as poor hygiene and improper handling by farmers, contributed to the spread of resistant pathogens like *S. aureus*. Farmers rely on cultural experience to diagnose and treat some disease conditions.

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