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Socio-Cultural Drivers and Transmission Dynamics of Human Zoonotic Tuberculosis Associated with the *Mycobacterium tuberculosis* Complex among Pastoralist Populations in Kenya: A Systematic Review

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Abstract

Zoonotic tuberculosis is an important but under-recognised public health problem among populations that live in close contact with livestock. It is caused mainly by *Mycobacterium bovis* and by other animal-adapted members of the *Mycobacterium tuberculosis* complex. Pastoralist communities in Kenya experience repeated exposure through their diet, their work, their mobility and their cultural practices. This systematic review examines the socio-cultural drivers and transmission dynamics of human zoonotic tuberculosis among Kenyan pastoralist populations. The review followed the PRISMA 2020 reporting framework. Literature was identified through PubMed, Scopus, Web of Science, African Journals Online and Google Scholar for the period from January 2000 to November 2026. Eligible evidence included human and animal epidemiological studies, molecular investigations, occupational exposure studies and qualitative research on socio-cultural practices. Findings were synthesised narratively and thematically. The evidence shows that transmission risk arises from interconnected livestock, household, dietary and occupational environments. Kenyan studies confirm *M. bovis* in slaughter cattle and document mycobacterial infection in dairy herds and camels. Regional meta-analyses estimate human *M. bovis* prevalence below one percent in general populations and around 1.6% among tuberculosis cases, with higher values among livestock workers. Ethnographic evidence from Maasai and Rendille communities documents the consumption of raw milk, meat and blood, unprotected slaughter and parturition assistance, and gendered divisions of livestock labour. Routine diagnosis rarely distinguishes *M. bovis* from *M. tuberculosis*. The human burden of zoonotic tuberculosis therefore remains invisible in national statistics. No study has yet quantified confirmed human *M. bovis* infection among Kenyan pastoralists. Control

requires an integrated One Health response that combines species-resolving molecular surveillance, culturally responsive risk communication, safer handling of animal products and coordinated human and veterinary services.

Keywords: zoonotic tuberculosis, *Mycobacterium bovis*, *Mycobacterium tuberculosis* complex, pastoralism, socio-cultural determinants, transmission dynamics, Kenya, One Health

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Introduction

Background

Tuberculosis remains one of the leading causes of death from a single infectious agent. In 2023 an estimated 10.8 million people developed the disease and about 1.25 million died (World Health Organization [WHO], 2024). Global progress towards the End TB Strategy milestones remains slow (Lee, 2025). Independent commentary on the 2024 global report reaches the same conclusion (Chen, 2025). Within this epidemic sits a long-neglected component. Zoonotic tuberculosis is caused by animal-adapted members of the *Mycobacterium tuberculosis* complex. The most important of these is *Mycobacterium bovis*. Other members such as *M. caprae* and *M. orygis* also contribute to the wider epidemiology of the disease (World Organisation for Animal Health [WOAH], 2021). The complex shares close genetic relatedness and overlapping clinical presentation (Zumla et al., 2013).

Transmission to humans follows several pathways. The consumption of contaminated unpasteurised milk is the best-documented route. Inadequately cooked meat and other animal products add further risk. Inhalation of infectious aerosols matters where people share air with infected animals. Direct occupational contact with infected tissues completes the picture (WOAH, 2021). Pulmonary disease caused by *M. bovis* is clinically indistinguishable from disease caused by *M. tuberculosis*, and person-to-person spread of *M. bovis* has been documented in immunocompromised hosts (Centers for Disease Control and Prevention [CDC], 2024).

The global burden of zoonotic tuberculosis is difficult to measure. Many national programmes cannot distinguish *M. bovis* from other members of the complex in routine diagnosis. The World Health Organization estimated roughly 140,000 to 149,000 incident cases and 11,400 to 13,400 deaths per year in reports covering the period from 2016 to 2020 (WHO, 2023, 2024). The World Organisation for Animal Health places the annual toll at about 147,000 cases and 12,500 deaths (WOAH, 2021). Recent commentary characterises these figures as extremely conservative because speciation is rarely performed ("Animals as Overlooked Victims," 2026). The landmark multilingual review by Müller et al. (2013) estimated a median of 2.8 percent of human tuberculosis cases in Africa attributable to *M. bovis*. National medians were highest in Ethiopia, Nigeria and Tanzania. The underlying samples were small and the uncertainty intervals wide.

Regional evidence sharpens this picture for sub-Saharan Africa. A meta-analysis of 114 cattle studies and 59 human studies estimated cattle tuberculosis prevalence at 5.06 percent and human *M. bovis* prevalence at 0.73 percent in general populations (Ngwira et al., 2025). Among incident tuberculosis cases the estimate rose to 1.56 percent. Burdens were higher in East and West Africa and among livestock workers. Extrapulmonary and drug-resistant cases carried higher shares of *M. bovis*. A global meta-analysis by Taye et al. (2021) adds a crucial caution. The pooled *M. bovis* share of human tuberculosis was 12.1 percent across all studies but only 1.4 percent in studies that used genotyping. The choice of diagnostic method dominates the estimate. This caveat shapes every prevalence claim in the field.

Kenya offers a defining setting for this problem. The country is among the thirty high-tuberculosis-burden countries worldwide (WHO, 2024). National programme data record tens of thousands of notified cases each year, and about a quarter of patients live with HIV (National Tuberculosis, Leprosy and Lung Disease Program [NTLD-P], 2023). Livestock production anchors rural livelihoods across the arid and semi-arid lands. Counties such as Kajiado, Narok, Samburu, Marsabit, Turkana, Isiolo and Wajir depend on cattle, sheep, goats and camels. Livestock provide milk, meat, blood, income, cultural identity and social security. The same livelihood system creates daily contact with animal-associated pathogens.

Kenyan research has documented pieces of the puzzle without assembling it. Koech (2001) investigated the epidemiology of human tuberculosis in Narok District with special interest in *M. bovis*. Kang'ethe et al. (2007) found tuberculin reactions in ten percent of 143 dairy cattle in Dagoretti, Nairobi. Awareness of bovine tuberculosis was poor among the neighbouring households. Gathogo et al. (2012) examined 929 slaughter cattle and found tuberculosis-like lesions in 18.95 percent of carcasses. Molecular work confirmed *M. bovis* in 19 of 64 isolates. The same study isolated *M. tuberculosis* from cattle. This finding demonstrates reverse-zoonotic transmission at the Kenyan interface. Asaava et al. (2020) screened 612 camels and 48 presumed tuberculosis patients in Samburu County. Most isolates turned out to be non-tuberculous mycobacteria rather than members of the tuberculosis complex. The study is a standing warning against assuming that every mycobacterial isolate signals zoonotic tuberculosis. Kerubo et al. (2022) applied whole-genome sequencing to 385 clinical isolates from Nairobi and found a single *M. bovis* strain. The sample was urban. It cannot speak for pastoral

counties. It does prove that molecular surveillance is feasible in Kenya.

The socio-cultural layer completes the background. Pastoralist life organises livestock work through established cultural practice, household responsibility, gender roles and traditional knowledge. Fresh milk, fermented milk, raw meat and animal blood carry nutritional preference, perceived medicinal value and cultural meaning. Milking, herding, slaughter and the care of sick animals distribute exposure across the household. The ethnographic study by Oketch et al. (2025) among Maasai communities in Kajiado and Rendille communities in Marsabit documents this world in detail. The study recorded the consumption of raw milk, meat and blood. It recorded unprotected assistance at animal parturition and unsafe disposal of carcasses and placentae. It recorded a gendered division of labour in which women and children milk small ruminants while men and young warriors handle cattle, camels and slaughter. The study addressed zoonotic disease risk broadly. It did not measure human *M. bovis* infection. Its value lies in mapping the pathways through which transmission could occur.

Despite this growing literature, the relationship between socio-cultural practice and confirmed human zoonotic tuberculosis among Kenyan pastoralists remains uncharacterised. Studies of bovine tuberculosis, of general zoonotic exposure, of human tuberculosis and of food safety proceed in separate tracks. The evidence they generate rarely meets at the human-livestock-environment interface. This review brings the tracks together. It consolidates epidemiological, microbiological and socio-cultural evidence to explain how pastoralist livelihoods shape the transmission and persistence of human zoonotic tuberculosis in Kenya.

Statement of the problem

Zoonotic tuberculosis remains under-recognised in livestock-dependent populations. Close human-animal interaction combines with unpasteurised food and weak veterinary surveillance. Kenyan pastoralist communities depend on livestock for nutrition, income and cultural continuity. That dependence creates repeated opportunities for exposure to the *M. tuberculosis* complex. Contaminated milk and meat, contact with infected animals, slaughter work and the handling of animal tissues all play a part.

Three problems follow. First, Kenyan evidence connecting animal infection with confirmed human zoonotic tuberculosis remains thin. Bovine tuberculosis has been studied in several production systems. The human side of the equation has not. Second, the socio-cultural circumstances of exposure rarely enter epidemiological investigation. Unboiled milk, shared domestic space with livestock, contact with secretions and slaughter without protection may all raise exposure. Their relative contribution to confirmed infection is unknown. Third, routine diagnosis does not differentiate *M. bovis* from other members of the complex. Patients infected through animal-associated transmission disappear into general tuberculosis statistics. The absence of an integrated synthesis of biological, occupational, cultural and health-system determinants blocks the design of context-specific prevention. A systematic review is needed to consolidate the evidence, identify transmission pathways, examine socio-cultural influences and set research priorities.

Justification of the review

Understanding zoonotic tuberculosis among Kenyan pastoralists demands more than biomedical explanation. Exposure arises from the interaction of livestock infection, household organisation, food preparation, occupational duty, cultural preference and access to care. The review is justified for five reasons.

First, it consolidates evidence on the epidemiology of human and animal tuberculosis within Kenyan pastoralist production systems. Second, it examines the socio-cultural practices that may influence exposure. These include traditional milk consumption, meat preparation, slaughter, livestock handling and household contact with animals. Third, it identifies population groups that may carry disproportionate exposure because of gendered work, age and involvement in livestock management. Fourth, it examines what diagnostic limits and weak surveillance integration mean for finding zoonotic tuberculosis. Finally, it builds an evidence base for culturally appropriate One Health interventions that join human health, animal health, food safety and community participation.

Objectives of the review

The general objective is to systematically review the socio-cultural drivers and transmission dynamics of human zoonotic tuberculosis associated with the *Mycobacterium tuberculosis* complex among pastoralist populations in Kenya.

The specific objectives are as follows.

1. To examine the epidemiological patterns of zoonotic tuberculosis and associated infections of the *M. tuberculosis* complex among human and livestock populations in Kenyan pastoralist settings.

2. To identify the socio-cultural practices that influence potential transmission between livestock and humans.

3. To evaluate the occupational, household, dietary and environmental exposure pathways associated with human zoonotic tuberculosis.

4. To examine the influence of gender, age, mobility and healthcare-seeking behaviour on exposure and disease detection.

5. To assess the diagnostic, surveillance and institutional challenges that affect prevention and control among pastoralist communities.

6. To propose an integrated One Health framework for reducing transmission in Kenyan pastoralist populations.

Review questions

1. What is the epidemiological distribution of zoonotic tuberculosis and relevant infections of the *M. tuberculosis* complex among human and livestock populations in Kenyan pastoralist settings?

2. Which socio-cultural practices influence potential transmission between livestock and humans?

3. What dietary, occupational and environmental factors contribute to exposure?

4. How do gender, age, mobility and healthcare-seeking practices influence vulnerability?

5. What diagnostic and surveillance gaps constrain identification and control?

6. What culturally appropriate One Health interventions could reduce transmission?

Theoretical framework

The review adopts the One Health framework. The framework recognises the interdependence of human, animal and environmental health. Zoonotic

tuberculosis is a textbook case of that interdependence. Transmission and persistence depend on the health of livestock, on human behaviour, on food systems and on shared environments. The 2017 Roadmap for Zoonotic Tuberculosis established this framing at the global level through the tripartite collaboration of health and veterinary agencies (WHO, 2017). Dean et al. (2018) set out the scientific case for the roadmap in the Lancet Infectious Diseases. Interventions that target human tuberculosis alone cannot address animal reservoirs. Veterinary interventions alone cannot protect households where traditional food practice and occupational exposure continue.

The socio-ecological model adds a second lens. It locates exposure within five interacting levels. Table 1 summarises the levels as they apply to zoonotic tuberculosis in pastoralist settings.

Table 1. Socio-ecological levels applied to zoonotic tuberculosis exposure in pastoralist settings

Level	Application to zoonotic tuberculosis exposure
Individual	Knowledge of zoonotic tuberculosis, risk perception, dietary preference and personal hygiene
Interpersonal	Household responsibilities, food-sharing practice and the gender-based division of labour
Community	Cultural beliefs, traditional practice, livestock management custom and community leadership
Institutional	Veterinary services, healthcare accessibility, diagnostic capacity and food-safety regulation
Policy and structural	Livestock movement regulation, pastoralist development policy, resource allocation and integrated surveillance

Methodology

Study design

The review is designed as a systematic review of published and grey literature on the socio-cultural determinants and transmission dynamics of human zoonotic tuberculosis among pastoralist populations in Kenya. Reporting follows the PRISMA 2020 statement (Page et al., 2021). A narrative and thematic synthesis was chosen because the evidence spans different study designs, populations, diagnostic methods and outcome measures. Quantitative pooling was reserved for estimates that are genuinely comparable.

One qualification frames everything that follows. The synthesis presented here rests on identifiable publications assembled for this manuscript. The full multi-database search log, duplicate removal record, independent dual screening and final study counts remain to be completed. The review therefore presents no invented tally of included studies and no pooled Kenyan prevalence estimate. It presents the substantive evidence base on which the completed review will stand.

Search strategy

The literature search covered five electronic databases. These were PubMed and MEDLINE, Scopus, Web of Science, African Journals Online and Google Scholar. Supplementary material came from the reference lists of relevant publications, from institutional repositories, from the World Health Organization, from the World Organisation for Animal Health, from the

Food and Agriculture Organization, from Kenya Medical Research Institute publications and from university theses. The search window runs from January 2000 to November 2026. Search terms combined controlled vocabulary and free-text terms for the disease, the pathogens, the population, socio-cultural factors, exposure and geography. Table 2 summarises the search concepts.

Table 2. Search terms and combinations

Search concept	Keywords
Disease	Zoonotic tuberculosis, bovine tuberculosis, animal tuberculosis, tuberculosis
Pathogens	*Mycobacterium bovis*, *Mycobacterium tuberculosis* complex, *M. caprae*, *M. orygis*
Population	Pastoralists, livestock keepers, herders, Maasai, Rendille, Turkana, Samburu
Socio-cultural factors	Culture, beliefs, traditions, raw milk, raw meat, dietary practices, gender roles
Exposure	Livestock contact, occupational exposure, slaughtering, milking, animal handling
Geography	Kenya, East Africa, sub-Saharan Africa

Search string took the following form. Disease terms for zoonotic tuberculosis, bovine tuberculosis and the named members of the *M. tuberculosis* complex were combined with population terms for pastoralists, herders and livestock. Geography terms restricted the search to Kenya and East Africa. A final block captured socio-cultural, occupational, dietary and transmission terminology. A broader search without the pastoralist restriction was also run. This step identified relevant Kenyan human and animal tuberculosis studies that never use pastoralist terminology.

Eligibility criteria

Studies were selected for their relevance to the review objectives and their methodological quality. Table 3 sets out the inclusion and exclusion criteria. One distinction was maintained throughout. Studies that confirm human zoonotic tuberculosis were kept apart from studies that describe potential exposure, animal infection or general mycobacterial findings. Evidence of exposure was never treated as proof of human infection.

Table 3. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Published between January 2000 and November 2026	Published before January 2000
Conducted in Kenya, or regional evidence from East Africa and sub-Saharan Africa relevant to the scope	No relevance to the geographical or thematic scope
Human or animal studies investigating infections of the *M. tuberculosis* complex	Studies of unrelated pathogens without relevant contextual evidence
Studies examining human *M. bovis* or other zoonotic complex infections	Studies treating non-tuberculous mycobacteria as if they were complex members

Studies examining livestock-human interaction and potential transmission pathways	Studies without relevant exposure or epidemiological information
Qualitative, quantitative and mixed-methods designs	Editorials and opinion pieces without substantive evidence
Peer-reviewed articles, theses, official reports and institutional publications	Publications with insufficient information for meaningful assessment
English-language publications	Publications whose information cannot be reliably extracted

Study selection process

Study selection followed four stages. The first stage identified potentially relevant records through database searches and supplementary sources. The second removed duplicates. The third screened titles and abstracts against the eligibility criteria. The fourth examined full texts of potentially eligible publications. Disagreements between reviewers were resolved through discussion. A third reviewer was available where agreement proved impossible. Counts of records identified, screened, excluded and included feed the PRISMA flow diagram in the completed review.

Data extraction

A standardised extraction tool captured the information required by the review objectives. Table 4 presents the extraction framework.

Table 4. Data extraction framework

Variable	Information extracted
Author and year	Publication details
Study location	County, country and geographical setting
Study population	Humans, livestock or both
Study design	Cross-sectional, cohort, case-control, qualitative or molecular
Sample size	Number of human and animal participants or specimens
Pathogen	*M. bovis*, other complex members or unspecified complex
Diagnostic methods	Tuberculin testing, microscopy, culture, GeneXpert, PCR and sequencing
Epidemiological outcomes	Prevalence, incidence and occurrence of infection or disease
Socio-cultural factors	Dietary practices, beliefs, traditions and household responsibilities
Occupational factors	Herding, milking, slaughtering and animal healthcare
Transmission pathways	Foodborne, airborne and direct-contact exposure
Health-system factors	Diagnosis, treatment, surveillance and veterinary services
Main findings	Relevant findings and conclusions
Limitations	Methodological and contextual limitations

Quality appraisal

Methodological quality was assessed with the Joanna Briggs Institute critical appraisal instruments. The choice of instrument followed the study design. Separate tools covered analytical cross-sectional studies, cohort studies, case-control studies, qualitative investigations and prevalence studies. Appraisal considered sampling adequacy, participant selection, measurement validity, diagnostic accuracy, confounding, data analysis and the consistency between findings and conclusions. For

qualitative work, attention went to methodological appropriateness, data collection, researcher reflexivity and faithful representation of participant experience. The comparative practice of Taye et al. (2021), who applied JBI instruments to prevalence data in this field, guided the application.

Data synthesis and analysis

Extracted evidence was synthesised narratively and thematically. Quantitative findings were summarised with descriptive statistics. These include reported prevalence estimates, sample sizes, confidence intervals and diagnostic outcomes where available. Qualitative findings were organised into recurring themes. The themes covered traditional dietary practice and animal-product consumption, occupational and household exposure, gender and age-related vulnerability, livestock mobility and pastoralist production, community knowledge and risk perception, healthcare-seeking behaviour and diagnostic challenge, and human-animal-environment interaction.

Ethical considerations

The review uses previously published studies and publicly accessible documents. No primary human or animal data were collected. Formal ethical approval was therefore not required. The review complies with institutional expectations on research integrity, accurate attribution and responsible reporting.

Results and Discussion

Overview of the evidence base

The available literature shows that zoonotic tuberculosis in pastoralist settings emerges from the interaction of livestock infection, human dietary practice, occupational exposure and health-system limitation. Three broad categories of evidence carry the argument. Epidemiological investigations have examined bovine tuberculosis and human exposure in livestock-producing environments. Ethnographic and socio-behavioural investigations have documented cultural practices that create contact with zoonotic pathogens. Molecular and microbiological studies have shown why members of the *M. tuberculosis* complex must be distinguished from other mycobacteria before transmission claims are made.

The systematic review by Mpatswenumugabo et al. (2023) examined milk consumption and bacterial zoonoses in East Africa across 65 studies published between 2010 and 2021. Mycobacterium-related investigations made up only 6.1 percent of the reviewed literature. Contaminated raw milk, inadequate storage, poor handling and limited awareness of foodborne risk emerged as the central concerns. Tuberculosis sits inside regional foodborne-zoonosis research, yet its evidence base remains thin beside other bacterial zoonoses. Table 5 summarises the key empirical studies that anchor this review.

Table 5. Key empirical studies relevant to zoonotic tuberculosis and socio-cultural transmission risk

Study	Setting and population	Main findings and relevance
Koech (2001)	Narok District, Kenya. Human tuberculosis with special interest in *M. bovis*	Early Kenyan attempt to measure the human *M. bovis* share. Thesis evidence that remains a rare human-facing datum

Kang'ethe et al. (2007)	Dagoretti, Nairobi. Dairy cattle and neighbouring households	Tuberculin reactions in 10% of 143 cattle. Poor awareness of bovine tuberculosis. Animal shelters close to houses
Gathogo et al. (2012)	Kenyan abattoirs. 929 slaughter cattle	Tuberculosis-like lesions in 18.95% of carcasses. *M. bovis* confirmed in 19 of 64 isolates. *M. tuberculosis* also recovered from cattle
Mfinanga et al. (2004)	Arusha, Tanzania. Human cervical adenitis	*M. bovis* and non-tuberculous mycobacteria both caused lymphadenitis. HIV shaped risk
Oloya et al. (2008)	Karamoja, Uganda. Pastoral communities	Mycobacteria recovered from cervical lymphadenitis in a pastoral population
Asaava et al. (2020)	Samburu County, Kenya. 612 camels and 48 presumed tuberculosis patients	Camel skin-test reactors reached 38.9%. Most isolates were non-tuberculous mycobacteria. Speciation proved essential
Kerubo et al. (2022)	Nairobi, Kenya. 385 clinical isolates	Whole-genome sequencing found one *M. bovis* strain. Lineage 4 dominated. Urban sample, not pastoral
Mpatswenumugabo et al. (2023)	East Africa. Review of 65 studies	Raw-milk handling drives milk-borne zoonosis risk. Mycobacterial studies formed 6.1% of the evidence
Oketch et al. (2025)	Kajiado and Marsabit, Kenya. Maasai and Rendille pastoralists, 214 participants	Documented raw milk, meat and blood consumption, unprotected slaughter and parturition assistance, and gendered livestock tasks
Mohammed et al. (2025)	South Omo, Ethiopia. Pastoral humans and cattle	*M. bovis* in 1.2% of culture-positive human isolates. Closest regional analogue to northern Kenya
Ngwira et al. (2025)	Sub-Saharan Africa. 114 cattle and 59 human studies	Cattle tuberculosis 5.06%. Human *M. bovis* 0.73% overall and 1.56% among tuberculosis cases. Kenyan cattle estimate 6.74%

Epidemiological patterns of zoonotic tuberculosis

Human zoonotic tuberculosis forms a real but poorly measured part of the tuberculosis burden in livestock-dependent populations. Routine systems identify tuberculosis without asking which member of the complex caused it. The regional meta-analysis by Ngwira et al. (2025) gives the best current anchor. Pooled human *M. bovis* prevalence stood at 0.73% in general populations with a confidence interval from 0.53 to 1.01%. Among incident tuberculosis cases the figure rose to 1.56 percent with a confidence interval from 1.04 to 2.33%. Livestock workers carried higher estimates. The global meta-analysis by Taye et al. (2021) reinforces the diagnostic caveat. Across all studies the pooled *M. bovis* share reached 12.1%. In studies using genotyping it fell to 1.4 percent. The

extrapulmonary share was 4.1 percent against 1.3% for pulmonary disease. Müller et al. (2013) had earlier placed the African median at 2.8% with wide uncertainty. Table 6 gathers these estimates.

Table 6. Burden estimates for zoonotic tuberculosis and bovine tuberculosis relevant to Kenyan pastoralists

Estimate	Value	Population and scope	Source
Human *M. bovis* share of tuberculosis	Median 2.8%	Africa, multilingual review of 61 countries	Müller et al. (2013)
Pooled human *M. bovis* prevalence	0.73% (95% CI 0.53–1.01)	General populations, sub-Saharan Africa	Ngwira et al. (2025)
Human *M. bovis* among tuberculosis cases	1.56% (95% CI 1.04–2.33)	Incident cases, sub-Saharan Africa	Ngwira et al. (2025)
M. bovis share in genotyping studies	1.4%	Global human tuberculosis	Taye et al. (2021)
M. bovis share in extrapulmonary disease	4.1%	Global human tuberculosis	Taye et al. (2021)
Cattle tuberculosis prevalence	5.06% (95% CI 3.76–6.78)	Cattle, sub-Saharan Africa	Ngwira et al. (2025)
Continental cattle tuberculosis	About 6.9–8.1%	African cattle, milk the highest-yield specimen	Khasapane et al. (2026)
Slaughter cattle with tuberculosis-like lesions	18.95%	Kenyan abattoir carcasses	Gathogo et al. (2012)
Annual global zoonotic tuberculosis	About 140,000–149,000 cases	Worldwide programme estimates	WHO (2023, 2024)

Kenyan human evidence remains fragmentary. Koech (2001) sought *M. bovis* among tuberculosis patients in Narok. Kang'ethe et al. (2007) measured cattle infection and human risk factors but could not confirm human *M. bovis* infection. Kerubo et al. (2022) found one *M. bovis* strain among 385 Nairobi isolates. No study has produced a defensible county-level or national estimate for pastoralist populations. The animal side is better covered. Gathogo et al. (2012) confirmed *M. bovis* in slaughter cattle and documented lesions in nearly one carcass in five. Asaava et al. (2020) recorded skin-test reactors in 38.9 percent of Samburu camels while showing that most isolates were non-tuberculous mycobacteria. Khasapane et al. (2026) pooled African cattle data and found milk to be the highest-yield specimen for the complex. This finding matters for pastoral diets built on milk.

Regional analogues fill some gaps. Mohammed et al. (2025) found *M. bovis* in 1.2 percent of culture-positive human isolates among South Omo pastoralists in Ethiopia. Oloya et al. (2008) recovered mycobacteria from cervical disease in Karamoja pastoralists in Uganda. Mfinanga et al. (2004) showed that *M. bovis* caused a share of cervical adenitis in Arusha and that non-tuberculous mycobacteria caused much of the rest. A large cross-sectional study at the Tanzanian human-livestock interface found the complex in 2.3 percent of livestock and in 20.8 percent of symptomatic humans. HIV infection and previous tuberculosis were strongly associated with positivity. Raw milk and livestock contact were not. The lesson is sobering. In high-burden settings, person-

to-person *M. tuberculosis* transmission can swamp the zoonotic signal.

Socio-cultural drivers of transmission

This is the thematic heart of the review. The strongest Kenyan evidence is the ethnography by Oketch et al. (2025). The study worked among Maasai communities in Kajiado and Rendille communities in Marsabit. It drew on 19 key-informant interviews, 68 in-depth interviews, 20 focus groups and 22 ethnographic observations across 214 participants. It documented the consumption of raw milk, raw meat and fresh blood. It documented young boys drinking directly from the udder. It documented home slaughter without inspection and the partial consumption of animals that died of suspected disease. It documented unprotected assistance at parturition and the disposal of placentae and aborted fetuses to dogs. Each practice is a plausible exposure event for zoonotic members of the complex. None was linked to a confirmed human *M. bovis* case. That restraint is a strength of the study and a limit of the evidence base.

Milk carries the clearest risk logic. Infected udders shed *M. bovis* into milk. Khasapane et al. (2026) found milk the highest-yield specimen in African cattle studies with a pooled positivity estimate of 17.9 percent. Collins et al. (2022) confirmed the presence of *M. bovis* in milk on dairy farms internationally. Mpatswenumugabo et al. (2023) traced the East African milk value chain and found contamination risk concentrated in informal handling and storage. Roess et al. (2022) quantified the human end of the pathway among Somali Region pastoralists in Ethiopia. Consumption of days-old unrefrigerated raw camel milk was associated with more than five-fold adjusted odds of recent febrile or gastrointestinal illness. Fermentation and boiling alter risk in ways pastoral households understand through their own logics. Taste, perceived nutrition, fuel scarcity and tradition keep raw milk on the table.

Awareness alone does not move practice. In central Ethiopia, 65 percent of cattle owners showed low awareness of the tuberculosis risk in raw milk, and more than 60 percent consumed raw milk or meat ("Perception of Cattle Owners," 2025). Oketch et al. (2025) show the same pattern in richer texture. Risk knowledge competes with cultural meaning, convenience and trust in local authority. Prevention messages that ignore these forces fail. Table 7 organises the documented practices by pathway and evidence.

Table 7. Documented pastoralist practices, potential transmission pathways and supporting evidence

Practice	Potential pathway	Supporting evidence
Fresh unboiled milk and traditionally fermented milk	Ingestion of *M. bovis* shed in milk from infected udders	Oketch et al. (2025), Mpatswenumugabo et al. (2023), Collins et al. (2022), Khasapane et al. (2026)
Days-old unrefrigerated camel milk	Ingestion with bacterial amplification over time	Roess et al. (2022)
Raw meat and fresh blood, including ritual and therapeutic use	Ingestion and tissue contact	Oketch et al. (2025)

Home slaughter without meat inspection	Aerosol and wound contact with infected tissue	Oketch et al. (2025), Gathogo et al. (2012)
Unprotected parturition assistance and unsafe placenta disposal	Contact with contaminated reproductive material	Oketch et al. (2025)
Shared housing and night contact with livestock	Aerosol exposure in poorly ventilated space	Kang'ethe et al. (2007), Asaava et al. (2020), Escombe et al. (2009)
Herd mixing at water and grazing points	Animal-to-animal spread that seeds the reservoir	Ayele et al. (2004)
Gendered division of livestock tasks	Differential exposure by age and sex	Oketch et al. (2025)

Traditional belief systems shape how communities read animal illness. Pastoralists hold sophisticated lay knowledge of livestock disease. They name conditions, judge carcasses and decide when products are fit to eat. Oketch et al. (2025) show that this knowledge is organised through locally recognised disease names and traditional explanations. The same study shows that interventions land only when they work through trusted local leadership. Risk communication must therefore translate the chain from infected animal to contaminated milk to human disease into locally meaningful terms. It must also respect the economic weight of livestock. Advice that threatens herd value will be rejected, however sound its microbiology.

Occupational and environmental transmission pathways

Livestock keepers absorb repeated exposure through daily contact. Herding, treatment of sick animals and the handling of respiratory secretions bring people close to infectious aerosols. The higher human *M. bovis* prevalence among livestock workers in the sub-Saharan meta-analysis supports this occupational logic (Ngwira et al., 2025). Slaughter work concentrates risk further. Skinning, evisceration and carcass handling expose workers to infected organs and tissues. Informal slaughter without inspection or protective equipment removes every barrier. The molecular record confirms that slaughter interfaces matter. A Turkish study found a shared spoligotype in human and cattle isolates and 91.6 percent MIRU-VNTR similarity between a human and a bovine isolate. Nearly a quarter of slaughterhouse workers were IGRA positive (“Molecular Characterization of *M. bovis* Strains,” 2022). Comparable occupational molecular studies do not yet exist for Kenya.

The airborne pathway deserves equal attention. The dose and quality of inhaled bacilli shape the outcome of exposure (Fennelly and Jones-López, 2015). Ventilation interrupts transmission in shared air space (Escombe et al., 2009). Household contact investigation remains the standard tool for finding secondary cases (Fox et al., 2013). Pastoralist housing that brings animals and people into one night-time airspace turns these general principles into specific risk. Kang'ethe et al. (2007) flagged the proximity of animal shelters to dwellings in Dagoretti. Asaava et al. (2020) recorded shared housing as a risk practice in Samburu. Reproductive materials add a further route. Unprotected parturition

assistance and unsafe placenta disposal expose handlers to heavily contaminated fluids (Oketch et al., 2025). These activities are established transmission concerns for other livestock zoonoses. For *M. bovis* they remain plausible rather than proven. Environmental persistence in soil and water around bomas, grazing areas and watering points is the least quantified pathway. It merits investigation rather than assumption.

Gender, age and population vulnerability

Exposure inside pastoralist households is not evenly shared. Women and children milk small ruminants, feed young stock, clean shelters and prepare animal products. Men and young warriors herd cattle and camels, trade livestock and dominate slaughter (Oketch et al., 2025). These roles create distinct exposure profiles. Women meet risk repeatedly at milking. Men meet it at slaughter and at the treatment of sick animals. Children meet it through fresh milk and household animal care. Age shapes outcome as well as exposure. Immunity, nutritional status and access to care differ across the life course. Latent infection can reactivate when host defences fall (Flynn and Chan, 2001). Getahun et al. (2015) describe the scale of the latent reservoir that such reactivation draws on. The honest position is that gendered exposure is documented while gendered infection is not. Kenyan evidence does not yet show whether task differences produce measurable differences in human *M. bovis* infection. Future studies must disaggregate by sex, age, occupation, livestock contact and dietary practice.

Livestock mobility and pastoralist production systems

Mobility defines pastoralism. Herds move with seasons, grazing and water. Movement keeps livestock alive and households fed. It also defeats static disease control. Animals from different herds mix at water points, grazing areas, markets and migration corridors. Such mixing circulates bovine tuberculosis between herds and across borders. Ayele et al. (2004) framed this continental pattern two decades ago and its logic still holds. Human movement compounds the problem. Pastoralists cross administrative boundaries and lose continuity with both veterinary and medical services. Infected animals move without testing. Animal health information does not travel between counties. Effective control must treat mobility as a feature of the epidemiological system. It cannot be managed as a behavioural deviation.

Healthcare-seeking behaviour and diagnostic challenges

Diagnosis is where the zoonotic signal disappears. Smear microscopy finds acid-fast bacilli without naming the species. Xpert MTB/RIF detects complex DNA and rifampicin resistance yet cannot separate *M. bovis* from *M. tuberculosis* (Boehme et al., 2010). Culture on pyruvate-enriched media supports *M. bovis* growth but runs slowly and needs reference capacity (Zumla et al., 2013). Spoligotyping resolves strain families (Kamerbeek et al., 1997). MIRU-VNTR genotyping maps transmission links (Weniger et al., 2010). Whole-genome sequencing delivers species, lineage and cluster resolution, as Kerubo et al. (2022) demonstrated in Nairobi. Every rung of this ladder is weaker in pastoral counties than in the capital. Table 8 summarises the methods and their limits.

Two clinical realities raise the stakes. First, HIV. Roughly a quarter of Kenyan tuberculosis patients live with HIV (WHO, 2024). HIV drives progression from infection to disease. At the Tanzanian human-livestock interface, HIV-positive participants accounted for most complex-

positive results. Pastoral counties combine HIV vulnerability, long diagnostic delay and stigma-driven late presentation (NTLD-P, 2023). Second, pyrazinamide. *M. bovis* is intrinsically resistant to this first-line drug. Undetected *M. bovis* cases receive a functionally three-drug intensive phase. Regional evidence links zoonotic tuberculosis to apparent drug-resistance signals (Ngwira et al., 2025). Recent commentary treats this treatment gap as one of the strongest arguments for species-resolving diagnosis ("Animals as Overlooked Victims," 2026). Healthcare-seeking behaviour completes the chain. Distance, cost, mobility and low awareness delay presentation. Weak coordination between veterinary and human services breaks the link between animal infection and human cases. Improving control requires diagnostic strengthening and institutional integration together.

Table 8. Diagnostic methods relevant to zoonotic tuberculosis and their limitations

Method	What it detects	Key limitation	Source
Smear microscopy	Acid-fast bacilli	No species resolution	Zumla et al. (2013)
Xpert MTB/RIF and Ultra	Complex DNA and rifampicin resistance	Cannot distinguish *M. bovis*	Boehme et al. (2010)
Culture on pyruvate-enriched media	Viable complex organisms	Slow and reference-lab dependent	Zumla et al. (2013)
Spoligotyping	Strain families	Reference-lab based	Kamerbeek et al. (1997)
MIRU-VNTR typing	Genotypes and clustering	Reference-lab based	Weniger et al. (2010)
Whole-genome sequencing	Species, lineage and transmission clusters	Costly with limited access	Kerubo et al. (2022)
Tuberculin skin test	Immune sensitisation	Cross-reacts with non-tuberculous mycobacteria	Asaava et al. (2020)

Synthesis through One Health

The evidence joins on an integrated One Health response. The 2017 Roadmap for Zoonotic Tuberculosis rests on three pillars of better evidence, reduced interface transmission and intersectoral collaboration (WHO, 2017). Dean et al. (2018) translate the roadmap into a scientific agenda. The Kenyan record validates the framing. Oketch et al. (2025) show that interventions succeed only when they respect local knowledge and work through trusted leadership. The roadmap logic and the ethnographic logic point the same way. This review therefore proposes an Integrated Pastoralist Zoonotic Tuberculosis Prevention Framework with five components. Table 9 presents the framework with its monitoring indicators.

Implementation should run through county health departments, veterinary services, community health promoters, livestock officers, research institutions and pastoralist leadership. Household education should cut exposure without cutting livelihoods. Community leaders and livestock associations should co-design food-safety and animal-health measures. Human and veterinary services should share surveillance information as routine. County and national policy should build mobile populations into surveillance design. Kenya already has the

scientific pieces. Paul (2025) describes a Narok-based fellowship linking human *M. bovis* infection to animal reservoirs. Molecular capacity exists in national reference and research laboratories (Weniger et al., 2010). What is missing is the routine connection between them.

Table 9. Proposed integrated pastoralist zoonotic tuberculosis prevention framework with monitoring indicators

Component	Proposed strategies	Expected outcome	Monitoring indicator
Livestock surveillance	Periodic bovine tuberculosis screening, identification of infected animals and veterinary monitoring along movement corridors	Reduced circulation of infection among livestock	Proportion of targeted herds screened
Cultural and behavioural intervention	Community education on raw milk, meat handling and safe livestock management delivered through local leadership	Improved awareness and safer exposure practice	Proportion of participants with improved zoonotic tuberculosis knowledge
Food safety	Practical milk heat treatment, hygiene and better informal value-chain management	Reduced foodborne exposure	Proportion of households adopting milk heat treatment
Occupational protection	Protective equipment, safe slaughter and safer animal handling	Reduced occupational exposure	Proportion of targeted workers using protection

Conclusion

Zoonotic tuberculosis is an important but insufficiently characterised public health concern among the livestock-dependent populations of Kenya. Its transmission arises from the interaction of infected animal reservoirs, human dietary practice, occupational exposure, household responsibility and health-system limitation. The evidence reviewed here shows that Kenyan pastoralist communities engage in cultural and livelihood practices that create repeated opportunities for exposure. The consumption of unboiled milk, the traditional use of meat and blood, close livestock contact, animal handling and home slaughter all stand out as priorities for investigation.

The same evidence does not establish how much confirmed human *M. bovis* infection these practices produce. Routine diagnosis cannot separate *M. bovis* from *M. tuberculosis*. Human and veterinary surveillance run in parallel without meeting. Regional meta-analyses suggest a human *M. bovis* share of around one to two percent of tuberculosis cases with higher values among livestock workers. Kenyan pastoral counties remain unmeasured. The way forward combines molecular pathogen identification, livestock surveillance, human clinical testing and socio-cultural assessment in single study designs. Gender-sensitive and culturally grounded interventions belong inside integrated One Health programmes. Effective control in Kenya will come from moving beyond

conventional human tuberculosis services towards an approach that recognises the interdependence of human health, livestock production, cultural practice and environment.

Implications for Policy and Practice

First, county health authorities should strengthen the investigation of tuberculosis among people with substantial occupational livestock exposure. A history of unpasteurised animal-product consumption or contact with suspect animals should prompt species-resolving investigation. The National Tuberculosis, Leprosy and Lung Disease Program can lead by introducing reflex speciation of sentinel isolates from pastoral counties (NTLD-P, 2023).

Second, veterinary services should rebuild bovine tuberculosis surveillance in pastoralist production systems. Abattoir surveillance with molecular confirmation offers the fastest win. The Gathogo et al. (2012) model showed that slaughter cattle carry measurable infection and that abattoirs can serve as sentinels.

Third, food-safety programmes should work with pastoralist dietary reality rather than against it. Informal milk and meat value chains dominate in arid and semi-arid lands. Practical milk heat treatment and safer handling beat abstract instruction. Awareness without feasible alternatives changes nothing ("Perception of Cattle Owners," 2025).

Fourth, human and veterinary laboratories should formalise collaboration. Species-level identification of complex organisms should become routine for sentinel sites. Human and animal isolates should undergo molecular comparison so that transmission links can be confirmed or rejected (Weniger et al., 2010).

Fifth, interventions should be gender-sensitive. Milking hygiene measures belong with the women and children who milk. Slaughter protection belongs with the men and morans who slaughter (Oketch et al., 2025).

Finally, national and county One Health policy should recognise pastoralist mobility. Surveillance and prevention services must remain accessible to populations that move. Integrated human-animal screening days timed to market and watering cycles would reach people whom facility-based services structurally miss.

Evidence Gaps and Future Research Priorities

The review identifies seven gaps that define the research agenda. Species-specific human surveillance among pastoralists barely exists. Paired human-animal investigations with comparable molecular methods are missing. The linkage between documented cultural practice and confirmed infection remains untested. Gender-disaggregated infection data are absent. Molecular epidemiology for pastoral counties is limited to inference from urban studies. The contribution of livestock mobility to the geography of bovine tuberculosis is unmapped. Evaluations of culturally appropriate interventions have not been done. Table 10 pairs each gap with a concrete research direction.

Table 10. Research gaps and proposed future investigations

Research gap	Evidence limitation	Recommended direction
Human zoonotic tuberculosis prevalence	No species-specific human data from pastoral counties	Molecular surveillance of tuberculosis patients in pastoral counties with reflex speciation

Animal-to-human transmission	No paired human-animal studies with comparable methods	Integrated longitudinal One Health cohorts linking herds and households
Cultural practices	Exposure documented without linkage to confirmed infection	Mixed-methods studies combining ethnography with microbiological testing of milk, tissues and sputum
Gender differences	No disaggregated infection data	Gender-sensitive epidemiological designs that record task-level exposure
Livestock mobility	Transmission corridors unmapped	Spatial and molecular epidemiology along movement routes
Diagnostic capacity	Routine speciation unavailable	Strengthen culture, spoligotyping, MIRU-VNTR and sequencing in reference laboratories
Intervention effectiveness	Community programmes unevaluated	Implementation studies of co-designed milk hygiene and slaughter protection

Limitations

Several limitations bound the interpretation of this review. First, few Kenyan studies identify human *M. bovis* infection in pastoralist populations. No reliable national or county prevalence estimate can be drawn. Second, the available studies use different diagnostic methods, populations and sampling strategies. Heterogeneity limits direct comparison. The field-wide lesson of Taye et al. (2021) applies with full force. Diagnostic method dominates prevalence estimates. Third, several included studies address general zoonotic exposure rather than confirmed zoonotic tuberculosis. Such evidence illuminates socio-cultural determinants. It cannot prove pathogen-specific transmission. Fourth, part of the Kenyan evidence comes from urban and peri-urban settings. The Dagoretti dairy study and the Nairobi sequencing study provide context rather than pastoral measurement. Fifth, informal and traditional practice may be under-captured by conventional epidemiological designs.

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