



EMERGING ZONOTIC BACTERIAL INFECTIONS: DIAGNOSTIC CHALLENGES AND PUBLIC HEALTH IMPLICATIONS

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Abstract

Emerging zoonotic bacterial infections represent a persistent and expanding global public health challenge, driven by intensified human–animal–environment interactions, climate change, urbanization, and globalization of food systems. These infections account for a substantial proportion of emerging infectious diseases worldwide and disproportionately affect low- and middle-income countries, where limited diagnostic capacity and fragmented surveillance systems hinder timely detection and response. Clinically, zoonotic bacterial diseases often present as non-specific febrile illnesses that overlap with endemic tropical infections, resulting in frequent misdiagnosis, underreporting, delayed treatment, and increased morbidity and mortality.

Conventional diagnostic methods, including culture and serology, remain constrained by low sensitivity, prolonged turnaround times, biosafety concerns, and cross-reactivity, while access to advanced molecular and genomic diagnostics is uneven across regions. Although polymerase chain reaction–based assays, multiplex panels, and next-generation sequencing have improved pathogen detection and antimicrobial resistance profiling, their implementation in endemic settings remains limited by cost, infrastructure, and workforce constraints.

This review synthesizes current evidence on the epidemiology, ecological and socioeconomic drivers, major emerging zoonotic bacterial pathogens, and the diagnostic challenges that impede effective clinical management and public health control. In addition, it examines surveillance gaps, outbreak potential, economic consequences, and the growing contribution of zoonotic pathogens to antimicrobial resistance. Emphasizing integrated solutions, the review highlights the critical role of the One Health approach in strengthening diagnostics, surveillance, prevention, and control strategies. Sustained investment in laboratory capacity, intersectoral collaboration, and climate-adaptive surveillance is essential to reduce the burden of zoonotic bacterial infections and enhance global health security.

Keywords: Zoonotic bacterial infections; Emerging infectious diseases; Diagnostic challenges; One Health; Public health surveillance; Molecular diagnostics; Antimicrobial resistance; Low- and middle-income countries

Introduction

Zoonotic bacterial infections, defined as diseases transmitted naturally between animals and humans, continue to represent a major and evolving global public health challenge. It is estimated that over 60% of known human infectious diseases and nearly 75% of emerging infectious diseases are zoonotic in origin, reflecting the close and complex interactions among humans, animals, and the environment. In recent years, the incidence and geographic distribution of zoonotic bacterial infections have increased, driven by rapid urbanization, deforestation, climate change, intensification of livestock farming, globalization of food systems, and increased human mobility.^{14,20}

Emerging zoonotic bacterial pathogens such as *Brucella* spp., *Leptospira* spp., *Coxiella burnetii*, *Campylobacter* spp., and non-typhoidal *Salmonella* continue to cause significant morbidity worldwide, particularly in low- and middle-income countries (LMICs). These infections frequently present as non-specific febrile illnesses, often indistinguishable from malaria, dengue, viral fevers, or tuberculosis, leading to frequent misdiagnosis and underreporting.⁶ Diagnostic challenges are further compounded by the limitations of conventional laboratory methods, including low culture sensitivity, prolonged incubation periods, biosafety concerns, and cross-reactivity in serological assays.⁷

Recent advances in molecular diagnostics, including polymerase chain reaction (PCR), multiplex syndromic panels, and next-generation sequencing (NGS), have improved the detection of zoonotic bacterial pathogens, particularly in culture-negative or atypical presentations. However, access to these technologies remains limited in many endemic regions due to cost, infrastructure constraints, and lack of trained personnel, perpetuating diagnostic inequities.⁵ As a result, the true burden of zoonotic bacterial infections is likely underestimated, hindering effective surveillance and outbreak response.

Beyond their clinical impact, zoonotic bacterial infections have substantial public health and economic consequences. Animal reservoirs play a critical role in the persistence and transmission of pathogens and in the emergence and spread of antimicrobial resistance (AMR), which poses an additional threat to global health security.¹⁹ Recognizing these interconnected challenges, the World Health Organization, along with other international agencies, strongly advocates for a *One Health* approach that integrates human, animal, and environmental health sectors to improve surveillance, diagnostics, and prevention strategies for zoonotic diseases.

In this context, a comprehensive review of emerging zoonotic bacterial infections, with particular emphasis on diagnostic challenges and public health implications, is timely and necessary. This review aims to summarize recent epidemiological trends, highlight current diagnostic limitations, and discuss integrated strategies for improved detection, surveillance, and control of zoonotic bacterial infections globally.

2. Epidemiology and Drivers of Emergence

2.1 Global distribution and burden

Emerging zoonotic bacterial infections are distributed worldwide but show the greatest burden in low- and middle-income countries (LMICs), particularly in tropical and subtropical regions where environmental, socio-economic, and ecological conditions favour transmission. Recent global estimates indicate that bacterial pathogens account for a substantial proportion of infectious disease-related mortality, with zoonotic-associated pathogens such as *Salmonella* and *Campylobacter* remaining among the leading causes of bacterial disease burden globally.¹³ Surveillance data and regional reports further demonstrate a persistently high incidence of food- and water-borne zoonoses

and continued endemicity of livestock-associated infections, including brucellosis and leptospirosis, across many LMIC settings.^{6,10}

Occupational and behavioural risk factors play a critical role in determining individual and community-level risk. People with frequent animal contact—such as farmers, abattoir and butchery workers, veterinarians, wildlife handlers, and informal animal traders—experience increased exposure to livestock and wildlife reservoirs, thereby elevating spill over risk. Food-handling practices, consumption of unpasteurised dairy products or undercooked meat, poor sanitation, and peri-urban backyard animal rearing are consistently reported contributors to zoonotic transmission in endemic regions. Informal animal trade and live-animal markets further intensify risk by creating repeated, high-density human–animal interactions that facilitate cross-species transmission and geographic spread of bacterial pathogens.¹

2.2 Environmental and ecological drivers

Climate variability and extreme weather events, including flooding, heavy rainfall, and rising temperatures, significantly influence zoonotic disease dynamics by altering reservoir host ecology and environmental persistence of bacterial pathogens. Leptospirosis outbreaks, for example, frequently follow flooding events because *Leptospira* spp. survive for prolonged periods in contaminated water and soil; climate change is expected to increase the frequency and intensity of such events, thereby expanding disease risk in vulnerable populations. Changes in vector and rodent ecology associated with environmental disruption also amplify transmission potential for rodent- and vector-borne zoonotic bacteria.¹⁶

Deforestation, land-use change, and agricultural intensification further increase zoonotic emergence by expanding the wildlife–livestock–human interface. Conversion of natural habitats into farmland or peri-urban settlements forces closer contact between humans, domestic animals, and wildlife, facilitating cross-species transmission and spill-over events. In parallel, intensive animal production systems concentrate large populations of susceptible hosts, enhancing pathogen amplification and accelerating microbial evolution under selective pressures such as widespread antimicrobial use. These interconnected environmental and agricultural drivers are consistently highlighted in One Health frameworks as central to contemporary zoonotic emergence.²⁴

2.3 Socioeconomic and health system factors

Socioeconomic vulnerability strongly shapes exposure to zoonotic bacterial infections. Poverty, limited access to safe water and sanitation, and reliance on informal food systems increase infection risk in many LMICs. Practices such as smallholder farming, home slaughtering, consumption of unpasteurised dairy products, and informal food markets are often economically necessary but bypass food safety and veterinary controls, allowing zoonotic pathogens to circulate along unregulated animal and food value chains.⁵

Weak surveillance systems, limited laboratory capacity, and fragmented reporting structures further hinder timely detection and response. Many endemic regions lack routine access to bacterial culture, molecular diagnostics, or validated serological assays, while inconsistent case definitions and poor integration between human and animal health sectors contribute to underreporting. These systemic gaps lead to delayed outbreak recognition, inappropriate empirical therapy, and missed opportunities for source control. International Tripartite and One Health initiatives consistently identify strengthening integrated surveillance and laboratory networks as a critical priority for mitigating zoonotic threats.²³

3. Major Emerging Zoonotic Bacterial Pathogens

3.1 Livestock-associated pathogens

Brucella species

Brucella species are among the most important livestock-associated zoonotic bacteria worldwide, particularly in LMICs where animal vaccination and pasteurization practices are suboptimal. Transmission to humans occurs through direct contact with infected animals or consumption of unpasteurised dairy products. Human brucellosis typically presents as a chronic febrile illness with osteoarticular, neurological, or cardiovascular complications, contributing to significant morbidity and economic loss. Despite control efforts in high-income countries, brucellosis remains endemic in many regions of Asia, Africa, and the Middle East.¹⁸

Leptospira species

Leptospira spp. are spirochetes maintained in the renal tubules of domestic and wild animals, particularly rodents and livestock. Human infection occurs through exposure to water or soil contaminated with animal urine. Leptospirosis is increasingly recognised as an emerging zoonosis associated with flooding, urban slums, and climate change. Clinical manifestations range from mild febrile illness to severe Weil's disease with renal and hepatic failure.¹⁶

Coxiella burnetii

Coxiella burnetii, the causative agent of Q fever, is transmitted primarily through inhalation of aerosols from infected livestock, especially sheep, goats, and cattle. The pathogen is highly infectious and environmentally resistant. Acute infection often presents as undifferentiated fever or pneumonia, while chronic infection may result in endocarditis. Underdiagnosis is common due to non-specific clinical features and reliance on specialized serological testing.¹⁷

3.2 Foodborne zoonotic bacteria

Salmonella (non-typhoidal)

Non-typhoidal *Salmonella* (NTS) remains a leading cause of foodborne zoonotic infections globally, transmitted through contaminated poultry, meat, eggs, and produce. While NTS typically causes self-limiting gastroenteritis, invasive disease is increasingly reported among children, older adults, and immunocompromised individuals, particularly in LMICs. The emergence of multidrug-resistant NTS strains poses additional public health challenges.⁶

Campylobacter species

Campylobacter spp., especially *C. jejuni*, are among the most frequently reported bacterial causes of gastroenteritis worldwide. Transmission is primarily linked to consumption of undercooked poultry, raw milk, and contaminated water. Although illness is usually mild, post-infectious sequelae such as Guillain-Barré syndrome underscore the pathogen's clinical significance. Global surveillance data indicate a rising burden in both high- and low-income settings.¹⁰

Escherichia coli (Shiga toxin-producing)

Shiga toxin-producing *Escherichia coli* (STEC) are important foodborne zoonotic pathogens associated with cattle reservoirs. Human infection may lead to hemorrhagic colitis and hemolytic uremic syndrome, particularly in children. Outbreaks linked to contaminated meat and fresh produce highlight the need for robust food safety measures across the production chain.¹⁵

3.3 Wildlife and vector-borne bacterial zoonoses

Yersinia pestis

Yersinia pestis, the causative agent of plague, persists in rodent reservoirs and is transmitted to humans via flea vectors. Although plague incidence has declined globally, sporadic outbreaks continue to occur in endemic regions of Africa, Asia, and the Americas. Ecological changes and

human encroachment into wildlife habitats contribute to the continued re-emergence of this historically significant zoonosis.³

Bartonella species.

Bartonella species are increasingly recognised as emerging zoonotic pathogens transmitted through arthropod vectors such as fleas, lice, and ticks. They are associated with a wide spectrum of clinical manifestations, ranging from mild febrile illness to endocarditis and neurological disease. Domestic animals and wildlife act as reservoirs, complicating surveillance and diagnosis.⁴

Francisella tularensis

Francisella tularensis, the agent of tularemia, is a highly infectious zoonotic bacterium transmitted through contact with infected wildlife, arthropod bites, or inhalation of contaminated aerosols. Human disease varies by route of exposure and can present with ulceroglandular, pneumonic, or systemic forms. Although relatively rare, tularemia remains a public health concern due to its potential for outbreaks and diagnostic difficulty.⁸

4. Clinical Manifestations and Diagnostic Dilemmas

4.1 Non-specific and overlapping clinical presentations

A defining feature of emerging zoonotic bacterial infections is their non-specific clinical presentation, which frequently manifests as acute febrile illness with headache, myalgia, malaise, and gastrointestinal symptoms such as diarrhea and abdominal pain.^{6,18} Infections such as brucellosis, leptospirosis, Q fever, and invasive non-typhoidal *Salmonella* may progress to multiorgan involvement, including hepatic, renal, pulmonary, neurological, or cardiovascular complications.^{16,17} The absence of pathognomonic signs often delays clinical suspicion, particularly during early disease stages.

4.2 Differential diagnosis in endemic settings

In endemic regions, zoonotic bacterial infections are frequently misclassified due to substantial clinical overlap with malaria, dengue, chikungunya, tuberculosis, enteric fever, and viral febrile illnesses.⁶ Gastrointestinal manifestations are often attributed to viral gastroenteritis, while pulmonary involvement may mimic community-acquired pneumonia. Syndromic management approaches, limited diagnostic testing, and high background prevalence of tropical infections further complicate accurate diagnosis.⁷

4.3 Delayed diagnosis and clinical outcomes

Delayed or missed diagnosis is associated with increased morbidity, mortality, and prolonged hospitalization, particularly in severe zoonoses such as leptospirosis and Q fever.^{16,17} Several infections may result in chronic or relapsing disease, including chronic brucellosis, Q fever endocarditis, and post-infectious complications such as renal failure or neurological sequelae.¹⁸ Diagnostic delay also facilitates ongoing transmission, especially in occupational and household settings.

5. Laboratory Diagnosis: Challenges and Advances

5.1 Conventional diagnostic methods

Conventional diagnosis relies primarily on culture and serological testing, both of which have significant limitations. Culture sensitivity is often low due to slow-growing or fastidious organisms, prior antibiotic exposure, and biosafety risks associated with pathogens such as *Brucella* spp. and *Coxiella burnetii*.¹⁷ Serological assays are widely used but are limited by cross-reactivity, delayed seroconversion, and inability to reliably distinguish acute from past infection.¹⁸

5.2 Molecular and genomic diagnostics

Advances in molecular diagnostics have substantially improved detection of zoonotic bacterial pathogens. PCR-based assays and multiplex syndromic panels enable rapid identification directly from clinical specimens, particularly in culture-negative cases.⁵ 16S rRNA gene sequencing is increasingly used for identifying rare or atypical pathogens in undifferentiated infections, while metagenomic and next-generation sequencing (NGS) approaches allow unbiased pathogen detection and antimicrobial resistance profiling.^{7,12} However, widespread implementation remains constrained by cost and technical requirements.

5.3 Point-of-care testing and field diagnostics

Point-of-care diagnostic tests play a critical role in outbreak investigations and resource-limited settings by enabling rapid, decentralized testing and early clinical decision-making.²¹ These tools are particularly valuable during natural disasters and humanitarian emergencies, although variability in diagnostic accuracy necessitates confirmatory testing where possible.

5.4 Diagnostic gaps in low-resource settings

Despite technological advances, major diagnostic gaps persist in low-resource settings. Inadequate laboratory infrastructure, high costs, limited reagent availability, and shortages of trained personnel restrict access to advanced diagnostics.⁵ Fragmented human–animal surveillance systems further limit timely detection and response. International One Health initiatives emphasize strengthening integrated surveillance, laboratory capacity, and workforce development as essential priorities.²³

6. Surveillance and Reporting Challenges

Effective surveillance is central to the prevention and control of zoonotic bacterial infections; however, substantial challenges persist globally. Underreporting and misclassification remain common, particularly in endemic regions, due to non-specific clinical presentations, limited diagnostic capacity, and reliance on syndromic management. As a result, zoonotic bacterial infections are frequently recorded under generic categories such as acute febrile illness or gastroenteritis, obscuring their true burden.⁷

A major limitation is the lack of integrated human–animal surveillance systems. In many countries, human health, veterinary, and environmental surveillance operate in parallel rather than as coordinated systems, limiting timely detection of spill-over events and shared outbreaks. The absence of data sharing across sectors delays source identification and weakens outbreak response.²³ Data gaps are particularly pronounced in low- and middle-income countries (LMICs), where laboratory infrastructure, reporting mechanisms, and trained workforce capacity are limited. These gaps result in incomplete epidemiological data, underestimation of disease incidence, and delayed recognition of emerging threats.¹³

Recent advances highlight the growing role of digital and genomic surveillance. Digital disease surveillance platforms, combined with pathogen genomics and whole-genome sequencing, enable early outbreak detection, tracking of transmission pathways, and identification of emerging variants. While these tools have demonstrated value in high-income settings, their implementation in LMICs remains constrained by cost, infrastructure, and technical expertise.²

7. Public Health Implications

7.1 Outbreak potential and epidemic preparedness

Zoonotic bacterial infections pose a significant outbreak and epidemic risk, particularly in settings with dense human–animal interactions and weak surveillance. Foodborne and waterborne zoonoses can spread rapidly through contaminated supply chains, while livestock- and wildlife-associated infections have the potential for cross-border transmission via trade, travel, and migration.

Globalization and climate-driven ecological changes further amplify these risks, underscoring the need for strengthened epidemic preparedness and early warning systems.^{3,21}

7.2 Economic and societal impact

Beyond their health effects, zoonotic bacterial infections impose substantial economic and societal costs. Direct costs include healthcare expenditure related to hospitalization, diagnostics, and treatment, while indirect costs arise from productivity loss, long-term disability, and premature mortality. In the agricultural sector, outbreaks can lead to livestock losses, trade restrictions, and reduced market confidence, disproportionately affecting smallholder farmers and rural economies in LMICs.¹¹

7.3 Antimicrobial resistance in zoonotic pathogens

Animal reservoirs play a critical role in the emergence and dissemination of antimicrobial resistance (AMR). The use of antimicrobials in food-producing animals selects for resistant bacteria that can be transmitted to humans through direct contact, food consumption, or environmental pathways. Zoonotic pathogens such as non-typhoidal *Salmonella*, *Campylobacter* spp., and *Escherichia coli* frequently exhibit multidrug resistance, complicating treatment and increasing reliance on broad-spectrum or last-line antibiotics.¹⁹

The spread of AMR among zoonotic bacteria has direct implications for empirical therapy, particularly in endemic settings where microbiological confirmation is delayed or unavailable. Inappropriate empirical treatment contributes to poor clinical outcomes and further selection of resistance, reinforcing the need for integrated One Health approaches to antimicrobial stewardship.²²

8. One Health Approach to Zoonotic Bacterial Infections

The One Health concept recognizes the interconnectedness of human, animal, and environmental health and provides a comprehensive framework for addressing zoonotic bacterial infections. The rationale for One Health is grounded in evidence that most emerging infectious diseases originate at the human–animal–environment interface, where ecological disruption, animal production systems, and human behavior converge.⁷ For zoonotic bacterial infections, this approach is particularly relevant, as pathogens are often maintained in animal reservoirs and influenced by environmental conditions.

Integrated surveillance systems are a core component of One Health. Linking human clinical surveillance with veterinary, wildlife, food safety, and environmental monitoring enables early detection of spill-over events and more effective outbreak response. The Tripartite Zoonoses Guide emphasizes that joint surveillance improves data completeness, reduces duplication, and supports risk-based interventions.²³

Effective One Health implementation requires intersectoral collaboration among public health authorities, veterinary services, environmental agencies, and policymakers. Such collaboration facilitates coordinated risk assessment, outbreak investigation, and control strategies that are not achievable through single-sector approaches.⁹

Several successful One Health case studies demonstrate the value of this approach, including coordinated brucellosis control through animal vaccination and human surveillance, integrated foodborne disease monitoring networks in Europe, and leptospirosis prevention strategies linking climate data with public health preparedness.^{10,16}

9. Prevention and Control Strategies

Effective prevention and control of zoonotic bacterial infections require interventions across the animal–human–environment continuum. At the farm level, biosecurity measures such as improved hygiene, controlled animal movement, vaccination of livestock, and safe waste management reduce pathogen transmission and environmental contamination.¹¹ Strengthening food safety systems, including pasteurization of dairy products, safe slaughter practices, and cold-chain maintenance, is essential for preventing foodborne zoonoses.

Occupational health measures are critical for high-risk groups such as farmers, abattoir workers, veterinarians, and wildlife handlers. Use of personal protective equipment, occupational health education, and regular health screening can significantly reduce exposure risk.¹

Vaccination strategies, where available, play an important preventive role. Animal vaccination against brucellosis and Q fever has demonstrated effectiveness in reducing human disease incidence, although implementation remains uneven in many LMICs.¹⁸ In parallel, public awareness and risk communication initiatives are vital to promote safe food handling, early healthcare seeking, and community engagement, particularly in endemic areas.

10. Future Perspectives and Research Priorities

Future efforts should prioritize strengthening diagnostic capacity, particularly in LMICs, through investment in laboratory infrastructure, workforce training, and quality assurance systems.⁵ The development of affordable, rapid molecular diagnostic tools, including point-of-care PCR and simplified sequencing platforms, is essential to improve early detection and case management in resource-limited settings.

Given the growing influence of climate change, climate-adaptive surveillance systems that integrate meteorological, ecological, and health data are increasingly important for predicting and preventing outbreaks of climate-sensitive zoonoses such as leptospirosis.¹⁶ At the policy level, improved integration of One Health principles into national and global health strategies, supported by sustained international collaboration and funding, is critical for long-term impact.²²

11. Conclusion

Emerging zoonotic bacterial infections continue to pose complex diagnostic, surveillance, and public health challenges worldwide, particularly in low- and middle-income countries. Non-specific clinical presentations, limited diagnostic capacity, fragmented surveillance systems, and socioeconomic vulnerabilities contribute to under recognition and delayed response. Early diagnosis, supported by improved laboratory and surveillance infrastructure, is essential to reduce morbidity, mortality, and transmission. Sustained implementation of One Health-based public health interventions, integrating human, animal, and environmental health sectors, represents the most effective strategy for preventing, detecting, and controlling zoonotic bacterial infections in an increasingly interconnected and climate-sensitive world.

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