



Epidemiology, Risk factors and One Health Approach to Overcome Tuberculosis of Zoonotic Importance

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ABSTRACT

Tuberculosis (TB) is one of the most important infectious diseases in the world that not only cause infection in people but also in animals. Tuberculosis is an important zoonotic disease with severe socioeconomic effects. Members of the *Mycobacterium tuberculosis* complex (MTBC), such as *M. tuberculosis* and *M. bovis* are the main etiological agents of this disease. Most affected regions include low-income areas like South-East Asia, Africa, and the Western Pacific, where the lack of access to healthcare, overcrowding, malnutrition, and poverty perpetuate the disease. HIV co-infection, diabetes, and malnutrition are the major risk factors of the host, whereas smoking, alcoholism, and being in close contact with infected people or animals are considered predisposing behavioral and occupational factors. The development of multi-drug-resistant tuberculosis (MDR-TB) has made controlling the disease even more difficult. One Health approach, the combination of human, animal and environmental health, offers a holistic approach to TB control. Nevertheless, there are problems in its implementation because of poor intersectoral co-ordination, insufficient diagnostic capacity, funding, and the lack of policy integration, especially in resource-constrained environments. This review highlights the major risk factors, its epidemiological aspects, and one health approach for the prevention and control of zoonotic TB.

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INTRODUCTION

Tuberculosis (TB) is considered one of the most important infectious diseases in humans and animals around the globe (Qureshi et al. 2023). *Mycobacterium tuberculosis* complex (MTBC), consisting of *M. tuberculosis* and a number of other organisms, including *M. canettii*, *M. bovis*, *M. caprae*, *M. microti*, *M. pinnipedii*, *M. mungi*, and *M. orygis* etc. present in animals and the environment, can cause zoonotic TB globally (Zhang et al. 2022). MTBC remains to be one of the leading causes of morbidity and mortality throughout the world. *M. tuberculosis* is the most common infectious in humans, and *M. bovis* causes TB in cattle and many other mammals, including humans, thus TB is an important

example of a zoonotic disease (Kock et al. 2021). TB, though a preventable and curable disease, is still among the top ten causes of death in the world and the most common cause of death caused by a single infectious agent, even in some areas more so than HIV/AIDS. According to the World Health Organization (WHO) Global Tuberculosis Report WHO, in 2019, 10 million individuals contracted TB disease of which about 1.2 million people died, and another 208,000 people died of the TB-HIV syndemic (Who 2020). According to one research WHO estimated that in 2022, 10.6 million individuals contracted TB, and 1.3 million people died of the disease. It is estimated that among these deaths 167,000 individuals were infected with TB/HIV. This makes TB the second largest infectious disease killer in

the world, after the COVID-19 (Yang et al. 2024). The lowest income countries, especially in South-East Asia, Africa, and Western Pacific are the highest burden. Bovine tuberculosis caused by *M. bovis* results in high economic losses in animals through reduced productivity, trade limitations, and euthanizing infected animals in bovines. Additionally, the zoonotic transmission of *M. bovis* to humans, mostly due to ingesting unpasteurized dairy products, direct contact with infected animals, or exposure to contaminated environments is an issue of significant concern to the public health, particularly in developing countries where human, animal, and environmental boundaries are usually unclear (Devi et al. 2021).

Tuberculosis epidemiology is multifactorial and is caused by biological, environmental and social determinants (Montgomery 2025). Immunosuppression including HIV co-infection, diabetes mellitus, malnutrition, smoking, and alcoholism are considered as host related factors that make a person more susceptible to infection and disease progression (Mwansumbule and Chuwa). The environmental and socioeconomic factors that help sustain and transmit TB in communities are poverty, overcrowding, poor ventilation, inaccessibility of healthcare systems and migration. In the animal population, disease maintenance and spread are caused by factors of intensive farming systems, non-existence of biosecurity measures, interspecies interactions, and the existence of wild animals' reservoirs (e.g., badgers, deer, elephants, and buffaloes). All these factors are interconnected as they show that TB is not only a biomedical problem but also a social and ecological one. The development and dissemination of multidrug-resistant (MDR) have made the control of global TB even more difficult (Millet et al. 2013) (Desouky et al. 2023). The emergence of MDR-TB, resistant against at least the two most effective first-line anti-TB medicines, isoniazid and rifampicin, is a severe threat to the general population and necessitates prolonged, more toxic, and costly treatment protocols (Abubakar 2024). Also, *M. bovis* is inherently resistant to pyrazinamide, which is among the fundamental medications in the primary TB treatment, which makes zoonotic TB even more difficult to treat (Borham et al. 2022). These issues support the necessity of new solutions beyond the traditional human-oriented disease control initiatives.

Due to the common surrounding of human beings as well as animals, the One Health approach has been receiving more attention in combating tuberculosis (Zhang et al. 2022). One Health is a multidisciplinary, multisectoral approach which acknowledges the interrelationship between human, animal and environmental health. The method facilitates research through coordination between the physicians, veterinarians, environmental scientists, the professionals in the field of public health, and policymakers to develop an integrated surveillance system, align diagnostic and reporting processes, and utilize integrative prevention and control strategies. The One Health paradigm can improve early warning of zoonotic infections between humans and animals and ecosystems, information exchange and rational antimicrobial usage in both industries to stop resistance (Erkyihun and Alemayehu 2022). The worldwide campaign against tuberculosis has also seen

much development with the efforts of the WHO, like the End TB Strategy (2016-2035), which plans to halve the TB cases and eliminate TB fatalities by 2035 (Marks et al. 2023). Nevertheless, the objectives cannot be achieved in most of the areas because of the continued socioeconomic inequalities, access to diagnostic care, underreporting, and poor cooperation between the veterinary and the governmental healthcare systems (Almuzaini and Alajaji 2025; Zahra et al. 2025). A transition of the independent control measures to combined One Health structure is necessary to attain sustainable TB elimination. This includes medical interventions as well as the enhancement of food safety, livestock control, surveying wildlife, and environmental sanitation (Zinsstag et al. 2023). In this regard, the epidemiological and risk factors of tuberculosis in the framework of One Health approach should be known to determine prevention and control measures.

This review will set out to present an overview of the epidemiology of tuberculosis on the global level, the key risk factors that contribute to the spread of this disease in humans and animals, and how the concept of One Health can be integrated to improve on surveillance, prevention, and eradication. This article allows us to reiterate the necessity of a united and holistic effort to end tuberculosis in the world by discussing the interconnection between human, animal and environmental health.

Epidemiology of Tuberculosis

Tuberculosis is a highly contagious infectious disease that is spread through close interaction between humans and animals (Navarro-Flores et al. 2022). Tuberculosis has a complicated epidemiology which is affected by a variety of factors such as socioeconomic status, environmental conditions, host immunity and characteristics of the pathogen (Hassine et al.). The World Health Organization (WHO, 2024) states that TB is one of the major causes of deaths in the world caused by a single infectious agent, which is ranked higher than HIV/AIDS in certain regions (World Health 2024b). The disease burden is not equally spread and approximately two-thirds of all TB instances take place in eight nations, namely India, China, Indonesia, the Philippines, Pakistan, Nigeria, Bangladesh, and the Democratic Republic of Congo (Lv et al. 2024). The African region has the highest rate per population due to the high HIV co-infection rates and due to the low access of healthcare and the South-East Asian region has the highest number of cases.

Conversely, the high-income countries have registered a gradual decrease in the incidence of TB because of the improved standards of living, sound public health strategies, and a strong surveillance framework. Nevertheless, migration, urbanization and international travel have seen the re-emergence of TB in some of the industrialized countries, and this has demonstrated the significance of international collaboration in the control of TB. These epidemiological patterns are needed to understand disease control, as well as to institute integrated measures within the One Health framework.

Human, Animal, and Zoonotic Tuberculosis

The *Mycobacterium tuberculosis* is the primary cause of Human TB and is spread via the air in the form of

airborne droplets, emitted when people with the active pulmonary disease sneeze and cough or speak. Latent TB may be reactivated due to factors like immunosuppression, HIV infection, malnutrition and diabetes. The emergence of multidrug-resistant TB (MDR-TB) in recent decades has become a major menace in the world. In 2023, the estimates provided by WHO show that the number of new cases of MDR/RR-TB (rifampicin-resistant TB) amounted to approximately 410,000 cases (Patel et al. 2025). These forms of TB that are resistant to treatment make treatment a challenging task and raise mortality rates, thus, the incorporation of drug resistance surveillance in TB epidemiology is a necessity.

In animals, *Mycobacterium bovis* is the primary cause of tuberculosis in cattle and a great variety of domestic and wild mammals (Kock et al. 2021). The disease is spread into human beings via consumption of unpasteurized milk or dairy products, inhalation of airborne particles of infected animals or direct contact with infected carcasses (Ogugua et al. 2021). A study detected *M. bovis* infection in three categories, i.e. farmers, animal handlers, and individuals in high TB areas in rates of 11.4, 8.9, and 12.6% respectively. The maximum number of people infected was in the group of residents that took unpasteurized milk and meat, indicating that consumption of raw milk and direct contact with TB patients are the most important risk factors to the spread of the disease (Bapat et al. 2017). Bovine tuberculosis is considered as a leading cause of significant economic losses within livestock industries through reduced productivity, trade restrictions and culling strategies (Tschopp et al. 2022). *M. bovis* is replicated in wildlife species including badgers, deer, buffaloes, elephants, and wild boars, which make it difficult to eradicate the disease through eliminating transmission sources. Those countries that have managed to have good surveillance and control of the disease include the UK, New Zealand and Australia because their veterinary infrastructure is robust and they have capacity to diagnose the disease. To some extent the disease has been controlled, however, in areas where the veterinary infrastructure is poor and lacks diagnostic capacity the disease is persistent. The contribution of zoonotic TB to the global TB burden is significant and underreported, especially in

rural and pastoral populations where human beings are in proximity with animals. Cross-sectional surveillance study conducted in three farms in Chennai to conduct tests on tuberculosis in cattle and animal handlers indicated that four cattle and six animal handlers were infected with the same strain of *M. tuberculosis*. The authors propose that cattle could have been infected by using contact with infected humans on multiple occasions (Palaniyandi et al. 2019). The transmission pathways are shown in Fig. 1

Tuberculosis (TB) is a multifactorial disease, and its occurrence and progression are caused by a complicated combination of biological, environmental, and behavioral factors (Sarwar et al. 2025). Although *Mycobacterium tuberculosis* is the main causative agent, it is evident that the host susceptibility, living conditions and lifestyle factors play a significant role in the development of an active disease. The greatest biological risk factor to active TB development is co-infection with Human Immunodeficiency Virus (HIV). HIV impairs the immune system, especially in draining off the CD4 + T lymphocytes, which are paramount in control of *M. tuberculosis* infection. The TB is also the top cause of death among the HIV/AIDS population as it claims almost a third of HIV-related deaths worldwide. TB and HIV have a two-way relationship as HIV exacerbates the disease of the latent TB infection, and TB enhances the replication of the virus and worsens the course of HIV infection (Mugo Moses). Hyperglycemia also disrupts the functioning of macrophage and lymphocyte which leaves the host powerless to contain the infection. The presence of diabetes and TB is a major health issue affecting the rest of the world, and in developing nations, the two are widespread health issues. In addition, diabetes may change the clinical manifestation of TB, slow down diagnosis, and minimize the treatment effect (Franco et al. 2024).

Malnutrition greatly affects the immune defense mechanisms of the host, making him more vulnerable to be infected with TB and deteriorate the disease. Protein-energy malnutrition undermines cellular immunity by lowering the production of cytokines, macrophage activity and T cells responses. Higher TB risk has also been linked to micronutrient deficiencies especially that of vitamin D, zinc and iron (Maaz et al. 2024). Areas

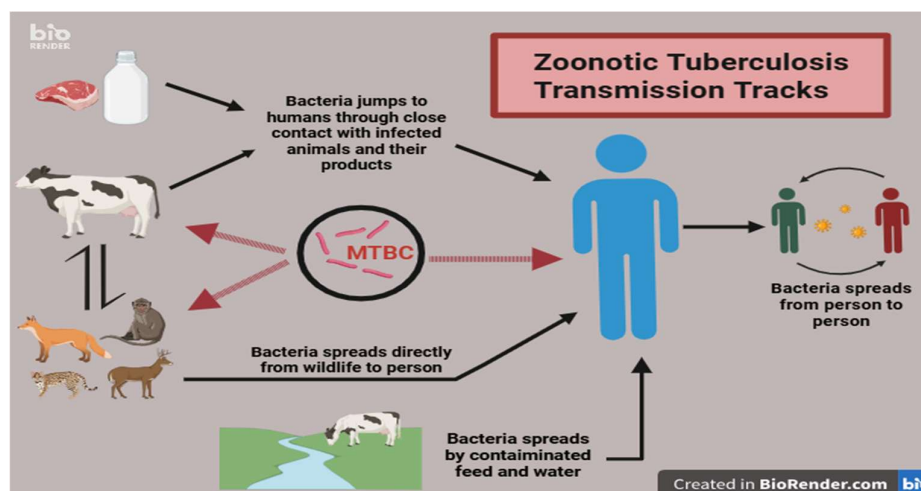


Fig. 1: Biological, environmental, and behavioral risk factors for tuberculosis

with low income are commonly affected by infectious disease, and nutritional support must be a core part of TB prevention programs. Poverty is one of the most powerful predictors of TB spread and ill health. It relates to poor nutrition, poor access to care, and poor diagnosis or care. Overcrowding also contributes greatly to the spread of TB since there will be high chances of being exposed to infectious droplets. It is especially clear in slums, in prisons, and in refugee camps and urban settlements where human beings live side by side (Etim et al. 2024).

The behavioral risk factor of TB infection and progression of the disease is cigarette smoking. The adverse effects of tobacco smoke are toxicity to the respiratory mucosa, weakening of the mucociliary clearance, and impairment of the macrophage activity, which predispose individuals to infection (Feldman et al. 2024). Smokers are at high risk of active TB (two-three times) and smoking is linked to slow sputum conversion and increased mortality in patients with TB. Passive smoking is also a risk factor causing TB in children and in household contact. Alcohol use impairs immunity and exposes an individual to more risk of contracting an infection and intravenous drug users are the most vulnerable group as they are more likely to be infected with HIV and because of social marginalization that makes the accessibility of medical services difficult. Other behavioral interventions like physical inactivity, stress, and insomnia might have an indirect effect on immune system and disease development (Yang et al. 2024).

Professional exposure is also contributory and especially in the case of healthcare providers, miners, and animal abattoir workers who are at a greater risk of infection because of their frequent exposure to infectious aerosols or animal reservoirs. Direct contact with *M. bovis* in livestock farmers and veterinarians poses a high zoonotic risk, highlighting the importance of personal protective equipment and health surveillance (Devi et al. 2021). These risk determinants should be understood to develop specific prevention and control interventions, especially in the concept of the One Health approach that involves examining the relationship of humans, animals, and the environment (Fig. 2).

Mycobacterium tuberculosis complex (MTBC) can infect animals within a maximum of three weeks of exposure to

contaminated pastures, highlighting the necessity to understand their environmental persistence and identification. The ability to identify the presence of MTBC in the environmental samples, including soil, water, air and fomites, is important to trace the source of infection and promote the One Health approach (the combination of human, animal, and environmental health in TB management). Under the WHO, OIE and FAO and the European Union long-term efforts, the combined objective is to decrease the percentage of deaths due to tuberculosis. by 95 percent and the prevalence of the tuberculosis rate by 90 percent by 2035 compared with 2015 (Chakaya et al. 2021).

In the present day, there are four broad types of methods in use to detect the presence of MTBC, including microscopic analysis, culture-based, molecular, and whole-genome sequencing (WGS). Microscopic analysis, commonly using Ziehl-Neelsen or fluorescent acid-fast staining, is an easy technique with sputum, soil, and water samples but not sensitive or specific (Ryan et al. 2014). The culture technique is the gold standard of verifying the presence of MTBC and it consists of decontamination by means of detergents and alkalis and inoculation on special agar like Lowenstein Jensen or Middlebrook (Cousins et al. 1989). Culture is expensive and less practical in resource-restricted environments though it is less time consuming than alternative methods since it may require up to eight weeks of incubation in the biosafety level 3 conditions though is reliable.

Faster alternatives have come up with molecular techniques such as conventional and real time PCR assays. These tests are aimed at the use of the genetic markers of the MTBC that are specific to the bacterium like 16S rRNA, IS6110, IS1081, and MPB70 genes and commercial tools like GeneXpert have improved diagnostic specificity and reduced the risk of contamination. Nevertheless, PCR based tests are limited by the low number of bacteria in environmental samples, the presence of inhibitors in soil or water and the lack of distinguishing between living and dead bacilli. To curb this, scientists are considering RNA based tests, especially those that identify 16S rRNA, to detect viable pathogens (Mao et al. 2025).

To further understand the dynamics of the transmission of TB, molecular typing and genotyping techniques are used



Fig 2: Global bovine tuberculosis (btb) detection and control program

to distinguish strains of the *Mycobacterium tuberculosis* and be able to trace the relation between human, animal, and environmental isolates including spoligotyping and MIRU-VNTR. As handy as they are, they are not always resolute enough to carry out detailed epidemiological studies. The most promising and the most developed tool is whole-genome sequencing (WGS) that allows a thorough study of the genomes of the MTBC using environmental samples (Afzal et al. 2023). It enables strains in large numbers to be sequenced simultaneously, and enables epidemiological studies of genetic differences and links, sources of infections, and transmission routes. WGS is an effective instrument in future molecular epidemiologic research and environmental TB surveillance as compared to the traditional methods, it is more accurate, faster, and cost-effective (Zhang et al. 2022). In one study it is stated that the chances of preventive treatment increases by using Interferon Gamma Release Assays (IGRAs) for detecting latent TB infection (LTBI) (Suárez et al. 2019; Hashem et al. 2023). The bovine tuberculosis (bTB) is a significant worldwide issue as it impacts the production of animals and human health with an estimated cost of approximately 3 billion dollars annually because of decrease in cattle performance, culling and trade limitations. Although developed countries have gone long way in managing bTB by conducting systematic eradication programs, still, it remains very difficult to eradicate bTB, and to maintain bTB-free status. The main pillar of bTB control in such countries as the USA and Europe has been the strategy of test and slaughter (or test and cull). This policy was introduced by United States in 1917 and then 232 million or more cattle were tested and pushed it to culling 3.8 million infected cattle by 1940 (Olmstead and Rhode 2004). These measures together with milk pasteurization significantly decreased the number of cases of human TB due to *M. bovis*, averting an estimated 25,000 deaths before chemotherapy was developed. The USDA has inclusive regulation on bTB control by its Uniform Methods and Rules (2005), where herd receives or renews its accredited status by periodic testing in the form of tuberculin skin tests and interferon-gamma tests. Likewise, the European nations also have "Officially TB Free (OTF) herd status but with similar method of testing. The presence of at least one positive animal leads to OTF withdrawal, quarantine and even slaughter of animals in the herd (Scientific Committee on Food European 2003; Lawes et al. 2016). Surveillance of slaughterhouses is extensively important in the monitoring of disease; in Northern Ireland, it contributes 18-28% of new herd infections. Field surveillance is therefore complemented by abattoir examinations and assists in the detection of undetected infections. Despite these achievements, the test-and-slaughter method is still hard to apply in the low- and middle-income nations because of the high prices, the lack of diagnostics, and economic waste because of the culling of the infected animals (Arnot and Michel 2020). In turn, bTB remains locally endemic in most developing areas, which means that cost-effective, sustainable, and locally relevant control efforts should be included in the overall concept of One Health (Ramanujam and Palaniyandi 2023).

One Health Approach and Challenges in Controlling Tuberculosis

The One Health approach presents a comprehensive system of treatment of tuberculosis (TB) as a common health issue at the interface between humans and animals and the environment (Table 1). It focuses on the medical, veterinary, and environmental sectors to prevent, detect, and control disease in the cross-species setting through collaborative work. Good practices have been the United States and European nations, where organized bovine TB control projects, milk pasteurization and monitoring of wildlife have reduced the transmission of zoonotic TB by a large margin. Likewise, combined strategies in New Zealand and some African countries include animal testing and environmental surveillance as well as population education to prevent the spread of human and bovine TB.

In this context, the human health sector is concerned with early diagnosis and effective treatment and monitoring of drug resistance, the animal health sector deals with herd testing, quarantine, vaccination, and control of infected livestock and the environmental sector continues with the observation of persistence and spread of *Mycobacterium* in soil, water and aerosol. The One Health approach offers an integrated, sustainable, and globally applicable approach to the control of tuberculosis and its eventual elimination by connecting the three pillars of the One Health approach through the sharing of information and integration of policies and research (Villa et al. 2023).

The adoption of the One Health approach to tuberculosis (TB) control has several practical, structural, and policy-related challenges, but it is also being associated with significant opportunities that can lead to improved global TB eradication endeavors due to innovation, collaboration, and integrated surveillance. The effectiveness of the approach is based on the ability to surmount existing barriers and use the new technologies, community participation, and evidence-based policymaking. Although the concept of One Health is increasingly being recognized, it has not been operationalized in the context of TB control because of the various challenges (Zhang et al. 2022).

One of the greatest barriers is the disjointed coordination of the human, animal, and environmental health sectors (na Phuket et al. 2025). Most countries continue to have their independent health systems where there is a distinct budget, surveillance data base and legal frameworks that make it difficult to share data and take common action. The other significant difficulty is the lack of diagnostic capacity and surveillance infrastructure especially in the low and middle-income nations where zoonotic TB and bovine TB are still prevalent. Lack of cheap and field adaptable diagnostic models to identify *Mycobacterium bovis* in both animal and human is a limiting factor towards early detection and response. Moreover, poor biosafety laboratories and lack of trained staff in veterinary microbiology and environmental monitoring also undermines TB monitoring (Khan et al. 2024).

There are also economic and logistical constraints which hinder effective implementation. The test and slaughter policy in the developed world cannot be applied in the resource-based setting because loss of livestock has a

Table 1: Epidemiology, risk factors, and one health approach to control Tuberculosis

Category	Aspect	Sources	Impact	Control/ Prevention Measures	References
Epidemiology	Causative Agent	<i>M. bovis</i> , <i>M. tuberculosis</i> , <i>M. africanum</i>	Causes pulmonary and extrapulmonary TB	Early diagnosis, PCR and culture-based testing	(Szacawa et al. 2025; Gcebe 2015)
	Transmission	Human-to-human, animal-to-human (zoonotic)	High transmission in crowded areas	Isolation, pasteurization, hygiene practices	(Quinn 2017)
	Geographic Distribution	Africa, Asia, Latin America	High morbidity and mortality	Strengthened surveillance and vaccination	(Sobe 2020)
	Host Range	Shared environment increases risk	Cross-species infection	Zoonotic monitoring and reporting	(Sibandze 2019)
Risk Factors	Environmental	Slums, livestock sheds	Increased airborne transmission	Improved housing, ventilation	(Bakker 2024)
	Nutritional	Undernourished populations	Reduced immunity	Nutrition programs and supplements	(Sinha et al. 2021)
	Occupational	Animal handlers	High exposure to infected aerosols	PPE, awareness training	(Devi et al. 2021; Mhlongo 2022)
	Immunological	Immunocompromised individuals	Reactivation of latent TB	Health screening and early treatment	(Sierra and Downs 2022)
	Socioeconomic	Rural communities	Delayed diagnosis and treatment	Free diagnostic and treatment programs	(Shah et al. 2022)
One Health Approach	Integration	WHO, OIE, FAO models	Effective disease control	Joint surveillance and data sharing	(Who 2022)
	Surveillance	Integrated reporting systems	Early outbreak detection	Real-time surveillance platforms	(Udegbe et al. 2023)
	Vaccination	BCG, new vaccine candidates	Reduced infection rates	Immunization programs	(Cho et al. 2021)
	Public Awareness	Schools, communities	Improved understanding and prevention	Awareness campaigns	(Abi et al. 2024)
	Research & Policy	Universities, ministries	Evidence-based control measures	Support for research and One Health policies	(World Health 2024a)

direct impact on livelihoods. Moreover, absence of political will, poor governance institutions and limited funding minimize the ability to have sustainable cross-sectoral efforts. The transmission of zoonotic in rural communities is still achieved through cultural practices including the consumption of untested milk or close contact between humans and animals. Finally, a low level of awareness and community involvement is a hindrance to change in behavior and makes disease prevention and control efforts less effective.

The challenge of institutionalizing the One Health approach is to be achieved by policy integration and governance reform. Governments, international agencies, including WHO, OIE (WOAH), and FAO, are promoting multi-sectoral TB action plans which incorporate human and animal health policies with coherent national structures. TB control can be equitable and sustainable by enhancing laws to combat animal diseases, compensation mechanisms on the culled livestock, and by ensuring One Health programs that are sustained to enable sustained funding (Bhatia 2021). Over an extended period, TB control initiatives can be changed by the connection between technological innovation, community involvement, and political dedication. The One Health approach (Fig. 3) does not only address cross-disciplinary weaknesses, but also makes sure that interventions are ecologically viable, socially acceptable and economically viable, which the path is leading to the ultimate eradication of tuberculosis as a global public health issue.

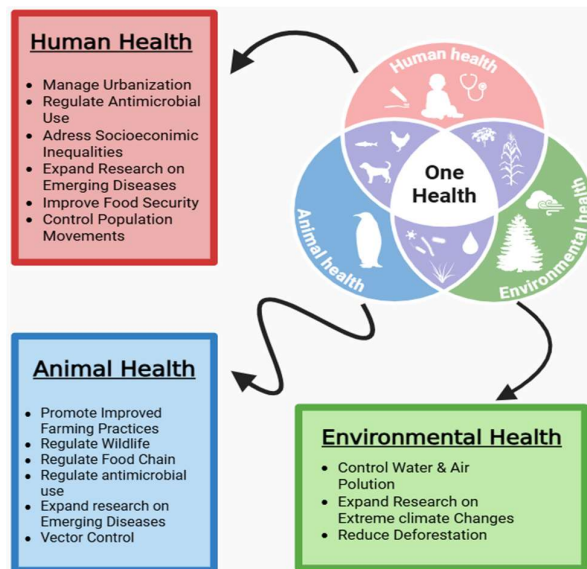


Fig 3: One Health triad, include human, animals and environmental factors

Conclusion

Tuberculosis continues to be an economic and public health issue of concern worldwide, and it is much rooted in the interrelatedness of the human being, the animal, and the environment. One Health approach is an integrated and sustainable model that brings together medical, veterinary and environmental fields to fight TB by sharing

surveillance, coordinating policies and communicating to the community. Through the enhancement of the quality of diagnostic capacity, intersectoral partnership, and the exploitation of technological advances, including those in molecular and whole-genome sequencing, countries can enhance the quality of early infections, track the spread routes, and adopt more efficient prevention initiatives. Nevertheless, meaningful progress depends on political will, sufficient funding and public consciousness to break the barriers of operation, especially in resource-restricted regions where the transmission of zoonotic is high. Finally, the adoption of One Health as a paradigm also will turn TB control into not just a biomedical effort but a global initiative, based on the principles of collaboration, equity, and sustainability, to ensure the ultimate eradication of the human and animal tuberculosis burden.

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REFERENCES

Abi DA, Magaji A, Al-Mansur S, Jang B, Ibrahim A, Gamde MS and Obeta M, 2024. Knowledge gaps in tuberculosis among students and its implications for public health; a review. *Microbes and Infectious Diseases* 5(1): 139-147.

Abubakar A, 2024. Evaluation of determinants, acceptability and effectiveness of community-based management of multidrug-resistant tuberculosis (mdr-tb) in Nigeria.

Afzal Z, Javed MT, Mohsin M, Ahmad HMW, Saeed Z, Taimoor M, Aleem RA, Raza A, Ayub A and Israr F, 2023. The usefulness of glutaraldehyde coagulation test as a conjuncture test in the diagnosis of tuberculosis in humans and animals. *Agrobiological Records* 15: 34-40.

Almuzaini AM and Alajaji AI, 2025. Epidemiology and public health importance of bovine salmonellosis 31(3): 341 (May-June).

Arnot LF and Michel A, 2020. Challenges for controlling bovine tuberculosis in south africa. *Onderstepoort Journal of Veterinary Research* 87(1): 1-8.

Bakker E, 2024. Urbanization and infectious disease dynamics: Examining the health risks of rapid urban growth. *Insight into Epidemiology* 1(1).

Bapat PR, Dodkey RS, Shekhawat SD, Husain AA, Nayak AR, Kawle AP, Dagainawala HF, Singh LK and Kashyap RS, 2017. Prevalence of zoonotic tuberculosis and associated risk factors in central indian populations. *Journal of Epidemiology and Global Health* 7(4): 277-283.

Bhatia R, 2021. National framework for one health. Food & Agriculture Org.

Borham M, Oreiby A, El-Gedawy A, Hegazy Y, Khalifa HO, Al-Gaabary M and Matsumoto T, 2022. Review on bovine tuberculosis: An emerging disease associated with multidrug-resistant mycobacterium species. *Pathogens* 11(7): 715.

Chakaya J, Khan M, Ntoui F, Aklillu E, Fatima R, Mwaba P, Kapata N, Mfinanga S, Hasnain SE and Katoto PDMC, 2021. Global tuberculosis report 2020—reflections on the global tb burden, treatment and prevention efforts. *International Journal of Infectious Diseases* 113: S7-S12.

Cho T, Khatchadourian C, Nguyen H, Dara Y, Jung S and Venketaraman V, 2021. A review of the bcg vaccine and other approaches toward tuberculosis eradication. *Human Vaccines & Immunotherapeutics* 17(8): 2454-2470.

Cousins DV, Francis BR and Gow BL, 1989. Advantages of a new agar medium in the primary isolation of mycobacterium bovis. *Veterinary Microbiology* 20(1): 89-95.

Desouky SM, Elgedawy AA, Abdel-Moein KA and Samir A, 2023. Bacteriological and molecular studies on mycobacterium bovis in cattle, with special reference to its antimicrobial resistance.

Devi KR, Lee LJ, Yan LT, Syaifinaz A-N, Rosnah I and Chin VK, 2021. Occupational exposure and challenges in tackling m. Bovis at human–animal interface: A narrative review. *International Archives of Occupational and Environmental Health* 94(6): 1147-1171.

Erkyihun GA and Alemayehu MB, 2022. One health approach for the control of zoonotic diseases. *Zoonoses* 2(1): 963.

Etim NG, Mirabeau Y, Olorode A and Nwodo U, 2024. Risk factors of tuberculosis and strategies for prevention and control. *International Journal of Innovative Healthcare Research* 12(1): 1-3.

Feldman C, Theron AJ, Cholo MC and Anderson R, 2024. Cigarette smoking as a risk factor for tuberculosis in adults: Epidemiology and aspects of disease pathogenesis. *Pathogens* 13(2): 151.

Franco JVA, Bongaerts B, Metzendorf MI, Risso A, Guo Y, Silva LP, Boeckmann M, Schlesinger S, Damen JAAG and Richter B, 2024. Diabetes as a risk factor for tuberculosis disease. *Cochrane Database of Systematic Reviews* (8).

Geebe N, 2015. The occurrence and molecular characterization of non-tuberculous mycobacteria in cattle, african buffalo (syncerus caffer) and their environments in south africa and genomic characterization and proteomic comparison with mycobacterium bovis. University of Pretoria (South Africa).

Hashem Z, Soliman R, El-Aziz MA, Badr Y and Aboul-Ella H, 2023. Development, preparation and evaluation of a murine monoclonal antibodies-based interferon-gamma enzyme-linked immunosorbent assay (elisa) for rapid and accurate diagnosis of bovine tuberculosis.

Hassine ABH, Marzouk M, Saad J, Boukadida J and Drancourt M, Molecular epidemiology of mycobacterium tuberculosis complex in the center of tunisia (2008-2010 and 2014-2017).

Khan J, Ali A, Khan S, Khan M, Mohsin S and Madsen C, 2024. Transformative advances in veterinary laboratory practices: Evaluating the impact of preliminary training in khyber

- pakhtunkhwa and balochistan provinces of pakistan. *Journal of Biosafety and Biosecurity* 6(4): 258-264.
- Kock R, Michel AL, Yeboah-Manu D, Azhar EI, Torrelles JB, Cadmus SI, Brunton L, Chakaya JM, Marais B and Mboera L, 2021. Zoonotic tuberculosis—the changing landscape. *International Journal of Infectious Diseases* 113: S68-S72.
- Lawes JR, Harris KA, Brouwer A, Broughan JM, Smith NH and Upton PA, 2016. Bovine tb surveillance in great britain in 2014. *Veterinary Record* 178(13): 310-315.
- Lv H, Wang L, Zhang X, Dang C, Liu F, Zhang X, Bai J, You S, Chen H and Zhang W, 2024. Further analysis of tuberculosis in eight high-burden countries based on the global burden of disease study 2021 data. *Infectious Diseases of Poverty* 13(1): 70.
- Maaz M, Sultan MT, Okoduwa SIR, Khalid MU, Asif A, Rafique M, Israr M and Ahmad M, 2024. The association and interactions of malnutrition, micronutrients, and drug therapy in the management of tuberculosis. *World Nutrition* 15(2): 102-114.
- Mao X, Wang J, Xu J, Xu P, Hu H, Li L, Zhang Z and Song Y, 2025. Current diagnosing strategies for mycobacterium tuberculosis and its drug resistance: A review. *Journal of Applied Microbiology* 136(5): 1xaf100.
- Marks GB, Teo AKJ, Wong EB and Fox GJ, 2023. Tuberculosis pandemic: Past, present and future global strategies. *The Challenge of Tuberculosis in the 21st Century: ERS Monograph* 101: 1.
- Mhlongo S, 2022. Occupational health and safety knowledge awareness and practices to prevent zoonotic diseases among veterinary services fieldworkers in the north west province, south africa. University of Johannesburg (South Africa).
- Millet J-P, Moreno A, Fina L, Del Baño L, Orcau A, De Olalla PG and Cayla JA, 2013. Factors that influence current tuberculosis epidemiology. *European Spine Journal* 22(Suppl 4): 539-548.
- Montgomery RM, 2025. The multifactorial determinants of tuberculosis mortality: A global comprehensive epidemiological analysis and framework for disease elimination.
- Mugo Moses H, Human immune system, its levels, and disorders in the context of hiv/aids: A comprehensive review.
- Mwansumbule MN and Chuwa AH, Beyond hiv: Prevalence and interaction of immunosuppressive conditions in patients with tuberculosis. *Annals of African Medicine*: 10-4103.
- na Phuket NR, Buahom J, Senaphan K, Sukon P, Sringam S, Angkititrakul S and Sringam P, 2025. International journal of veterinary science. *International Journal of Veterinary Science* 14(1): 212-218.
- Navarro-Flores A, Fernandez-Chinguel JE, Pacheco-Barrios N, Soriano-Moreno DR and Pacheco-Barrios K, 2022. Global morbidity and mortality of central nervous system tuberculosis: A systematic review and meta-analysis. *Journal of Neurology* 269(7): 3482-3494.
- Ogugua AJ, Onunkwo JI, Nwankwo IO, Basil-Ejidike RC and Nwanta JA, 2021. Tubercles in cattle carcasses and risk behaviours for zoonotic tuberculosis transmission among workers in a municipal slaughterhouse. *Notulae Scientiae Biologicae* 13(2): 10811-10811.
- Olmstead AL and Rhode PW, 2004. An impossible undertaking: The eradication of bovine tuberculosis in the united states. *The Journal of Economic History* 64(3): 734-772.
- Palaniyandi K, Kumar N, Veerasamy M, Kabir Refaya A, Dolla C, Balaji S, Baskaran D, Thiruvengadam K, Rajendran A and Narayanan S, 2019. Isolation and comparative genomics of mycobacterium tuberculosis isolates from cattle and their attendants in south india. *Scientific Reports* 9(1): 17892.
- Patel MN, Patel AJ, Nandpal MN, Raval MA, Patel RJ, Patel AA, Paudel KR, Hansbro PM, Singh SK and Gupta G, 2025. Advancing against drug-resistant tuberculosis: An extensive review, novel strategies and patent landscape. *Naunyn-Schmiedeberg's Archives of Pharmacology* 398(3): 2127-2150.
- Quinn K, 2017. A bioarchaeological study of the impact of mobility on the transmission of tuberculosis in roman britain.
- Qureshi MA, Fatima Z, Muqadas SML, Najaf DE, Husnain M, Moeed HA and Ijaz U, 2023. Zoonotic diseases caused by mastitic milk. Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan 4: 557-572.
- Ramanujam H and Palaniyandi K, 2023. Bovine tuberculosis in india: The need for one health approach and the way forward. *One Health* 16: 100495.
- Ryan GJ, Shapiro HM and Lenaerts AJ, 2014. Improving acid-fast fluorescent staining for the detection of mycobacteria using a new nucleic acid staining approach. *Tuberculosis* 94(5): 511-518.
- Sarwar MZ, Nomi ZA, Awais M, Shahbakht RM, Jamil M, Mussawar M, Yasin I, Hafsa Q, Abbas Q and Yousuf H, 2025. Effect of climate change on transmission of livestock diseases. *Agrobiological Records* 19: 1-11.
- Scientific Committee on Food European C, 2003. Health & consumer protection directorate-general. Opinion of the Scientific Committee on Food on additional information on “energy” drinks. Published March 5.
- Shah HD, Nazli Khatib M, Syed ZQ, Gaidhane AM, Yasobant S, Narkhede K, Bhavsar P, Patel J, Sinha A and Puwar T, 2022. Gaps and interventions across the diagnostic care cascade of tb patients at the level of patient, community and health system: A qualitative review of the literature. *Tropical Medicine and Infectious Disease* 7(7): 136.
- Sibandze B, 2019. Genotypic and phenotypic diversity of mycobacterium tuberculosis strains in patients with concomitant pulmonary and extra-pulmonary tuberculosis. University of Pretoria (South Africa).
- Sierra CJ and Downs CA, 2022. Screening and testing for latent tuberculosis infection among patients who are immunocompromised. *The Nurse Practitioner* 47(11): 32-39.
- Sinha P, Lönnroth K, Bhargava A, Heysell SK, Sarkar S, Salgame P, Rudgard W, Boccia D, Van Aartsen D and Hochberg NS, 2021. Food for thought: Addressing undernutrition to end tuberculosis. *The Lancet Infectious Diseases* 21(10): e318-e325.
- Sobe CJB, 2020. Zoonotic transmission of tuberculosis between the pastoralists and their livestock in south sudan western bahr el ghazal state.
- Suárez I, Füniger SM, Kröger S, Rademacher J, Fätkenheuer G and Rybniker J, 2019. The diagnosis and treatment of tuberculosis. *Deutsches Aerzteblatt International* 116(43)
- Szacawa E, Radulski Ł, Weiner M, Szulowski K and Krajewska-Wędzina M, 2025. Mycobacterium tuberculosis complex infections in animals: A comprehensive review of species distribution and laboratory diagnostic methods. *Pathogens* 14(10): 1004.
- Tschopp R, Zinsstag J, Conlan A, Gemechu G and Wood J, 2022. Productivity loss and cost of bovine tuberculosis for the dairy livestock sector in ethiopia. *Preventive Veterinary Medicine* 202: 105616.
- Udegbe FC, Nwankwo EI, Igwama GT and Olaboye JA, 2023. Real-time data integration in diagnostic devices for predictive modeling of infectious disease outbreaks. *Computer Science & IT Research Journal* 4(3): 525-545.
- Villa S, Carugati M, Rubach MP, Cleaveland S, Mpagama SG, Khan SS, Mfinanga S, Mmbaga BT, Crump JA and Raviglione MC, 2023. ‘One health’ approach to end zoonotic tb. *The International Journal of Tuberculosis and Lung Disease* 27(2): 101-105.

- Who FAO, 2022. Surveillance and information sharing operational tool.
- Who G, 2020. Global tuberculosis report 2020. Glob. Tuberc. Rep 2020
- World Health O, 2024a. Evidence and research gaps identified during development of policy guidelines for tuberculosis. World Health Organization.
- World Health O, 2024b. Who bacterial priority pathogens list, 2024: Bacterial pathogens of public health importance, to guide research, development, and strategies to prevent and control antimicrobial resistance. World Health Organization.
- Yang H, Ruan X, Li W, Xiong J and Zheng Y, 2024. Global, regional, and national burden of tuberculosis and attributable risk factors for 204 countries and territories, 1990–2021: A systematic analysis for the global burden of diseases 2021 study. BMC Public Health 24(1): 3111.
- Zahra N, Qureshi MA, Numan L, Abbas RZ, Husnain M, Saeed Z and Fatima Z, 2025. Epidemiological insights and public health implications of zoonotic bovine salmonellosis. Agrobiological Records 21: 122-133.
- Zhang H, Liu M, Fan W, Sun S and Fan X, 2022. The impact of mycobacterium tuberculosis complex in the environment on one health approach. Frontiers in Public Health 10: 994745.
- Zinsstag J, Kaiser-Grolimund A, Heitz-Tokpa K, Sreedharan R, Lubroth J, Caya F, Stone M, Brown H, Bonfoh B and Dobell E, 2023. Advancing one human–animal–environment health for global health security: What does the evidence say? The Lancet 401(10376): 591-604.