

Multilevel Risk Factors for Tuberculosis at the District Level in Punjab, India: A Comprehensive Global-to-Local Narrative Review

Jessy Juian^{1*}, Sudhakar Ranjan², Roopali Sood³

^{1*}Research Scholar, Apeeay Stya University. Email: jessymoljulian@gmail.com.

²Apeeay Stya University. Email: sudhakar.ranjan@asu.apeejay.edu.

³Apeeay College of Fine Arts. Email: Roopali.sood@learn.apeejay.edu.

Abstract

Background: Tuberculosis (TB) risk is the result of the interaction of biological, behavioural, environmental, socioeconomic and health system factors. They are locally relevant and need to be assessed carefully.

Objectives: This review aims

To synthesis and organize the health, demographic and epidemiological evidence relevant to TB risk in District Kapurthala, Punjab, India within a structured global to local framework.

To identify the highest risk factors to TB prevalence and control in this District.

Methods: This narrative review examined WHO reports, India's National TB Prevalence Survey, Punjab STEPS surveys, census and industrial profiles, and selected peer-reviewed literature. Evidence was organised into five domains within a global-to-local framework.

Results: TB infection prevalence was 22.6% nationally, while Punjab's 2014–2015 survey reported diabetes prevalence of 14.3%. Kapurthala's agrarian-industrial context suggests potential vulnerabilities linked to diabetes, migrant labour, and overcrowded housing; their contribution to local TB burden requires validation.

Conclusion: Diabetes-related TB screening, worker housing assessment, and continuity of care for migrants should be assessed locally. They need to be assessed in relation to each other through district surveillance and primary research to inform interventions.

Keywords: Tuberculosis; risk factors; Kapurthala; Punjab; India; diabetes mellitus; social determinants of health; narrative review.

1. Introduction

Tuberculosis (TB) is a communicable infectious disease caused by *Mycobacterium tuberculosis* with the lungs being the most commonly affected organ. Transmission occurs mainly through airborne respiratory particles generated by individuals with infectious pulmonary disease [1]. Despite substantial advances in diagnostic methods and effective treatment procedures, TB continues to cause considerable morbidity and mortality and making it a major global public health concern [1].

According to the WHO global Tuberculosis report 2025, an estimated 10.7 million people developed TB and 1.23 million died from the disease worldwide in 2024, corresponding to a global incidence rate of 131 per 100,000 population and a case fatality ratio of 11.5 % [1]. The net reduction in TB incidence between 2015 and 2024 was only 12% far short of the End TB Strategy milestone of a 50% reduction by 2025. And the sustained control efforts since 2000 are estimated to have averted around 83 million deaths [1].

In the context of TB, a risk factor refers to any biological, environmental, behavioural or social condition that increases the probability of exposure to infectious TB progression from infection to active disease or delay in diagnosis and treatment. Understanding these risk factors and how their relative importance varies across geographic and socio-economic settings is essential for designing targeted and locally appropriate TB elimination strategies [1], [5].

This review is structures to move from the global evidence base to the Punjab context and finally to the Kapurthala district using a standardized classification framework. A Pathogenesis pathway diagram, an overlap Venn diagram and comparative priority matrices are used to illustrate how risk factors compound and vary by setting.

1.1 Objectives

To collect, organise and critically analyse relevant published health and demographic data related to TB risk and prevalence and then moving systematically from the global and national context to the Punjab state and Kapurthala district context.

To identify and prioritize the key risk factors contributing to TB prevalence in Kapurthala district using a structured, multi-domain risk factor framework validated against national and state level evidence.

2. Methods

2.1 Review Design

This is a narrative review with a structured, framework guided synthesis, rather than a systematic review or an original primary data study. It was chosen because no dedicated, published, district level TB prevalence survey exists for Kapurthala. The review therefore synthesises the best available secondary evidence at global, national, state and district level to generate a locally relevant, evidence-based risk factor assessment and set of testable priorities for future primary research and programmatic action.

2.2 Data Sources

- WHO Global Tuberculosis Report 2025(global and regional burden estimates).
- India's National TB Prevalence Survey 2019-2021 (Central TB decision, Ministry of Health and Family welfare, with ICMR-National Institute for Research in Tuberculosis).
- Punjab state-wide STEPS non-communicable disease risk factor surveys (diabetes, hypertension, obesity, tobacco and alcohol use) .
- Census of India 2011, District census handbook and MSME industrial profile for Kapurthala
- Peer-reviewed literature indexed in PubMed, ScienceDirect and Google Scholar on TB risk factors in India, Punjab and comparable North India settings, together with National TB Elimination Programme (NTEP)/ Nikshay programme documentation.

2.3 Search and Selection Approach

Searches combined the terms “tuberculosis”, “risk factor”, “India”, “Punjab” and “prevalence survey” together with domain specific terms such as “diabetes”, “undernutrition”, “occupational”, migrant labour”. Sources published from 2011 onward were prioritised with earlier sources retained only where they provided foundational epidemiological or pathogenesis evidence still considered as current. Official Government and WHO reports were treated as primary sources for burden estimates, peer-reviewed studies were prioritised for risk-factor associations.

2.4 Analytical framework

Evidence was organized using a five-domain classification of TB risk factors such as biological, behavioural, environmental, socio-economic and health system factors.(Figure 1 shows these factors). These are applied consistently across the global, national, Punjab and Kapurthala section. This framework was then combined with a pathogenesis pathway model(shown in figure 2), an overlap model of compounding biological risk factors (shown in figure3) and a comparative priority matrix (shown in table 2) to move from descriptive synthesis towards a prioritised, locally actionable set of findings.

2.5 Limitation of Approach

Since this study is based on a narrative review and does not follow pre-registered protocol or systematic search strategy, some selection bias may be present. The findings related to Kapurthala are therefore based on available evidence and should be interpreted with caution. Due to the lack of district specific TB prevalence survey, the conclusions for Kapurthala were extrapolated from state level and national data. These limitations are discussed further in section 7

3. Results

3.1 Global Epidemiology of Tuberculosis

The global TB burden remains unevenly distributed across regions. The WHO South Asia, western pacific and African regions together account for the large majority of global TB cases. Eight countries such as India, Indonesia, the Philippines, China, Pakistan, Nigeria, the Democratic Republic of Congo and Bangladesh. These countries shares the burden of 67%of the global total with 30 high burden countries accounting for 87 % [1]. India alone accounts for approximately 25% of global TB cases. [1]. These regional differences are closely associated with structural factors such as overcrowded living conditions, poor nutrition, and limited healthcare access. It again collaborates with individual level risk factors like HIV infection, diabetes, smoking and alcohol use.

Latent TB Infection (LTBI) represents major challenge to global TB elimination efforts. Approximately one-quarter of the world's population is estimated to have LTBI creating a large reservoir of individuals at potential risk of developing active disease [1]. While most people with LTBI do not progress to active TB an estimated 5-10% do so over their lifetime. Progression become substantially more when additional factors such as HIV, diabetes or undernutrition are present. An untreated infectious case can transmit TB to as many as 15 close contacts annually, which further underscore the public health importance of this latent reservoir.

Drug resistant TB adds a further layer of difficulty to global control efforts. In 2024 an estimated 390,000 people developed rifampicin-resistant or multi-drug resistant TB (MDR/RR-TB). But yet only 42% of them were started on appropriate treatment [1] this gap reflects health system factors such as diagnostic delay and treatment interruption which interact with biological and behavioural risk factors to sustain constant transmission.

3.2 Global Classification Framework for TB Risk Factors.

TB risk factors are best understood as belonging to five interacting domains such as biological host factors, behavioural factors, environmental housing factors, socio economic factors and health system factors [3]. Figure 1 summarises this classification which is applied consistently throughout the remainder of this review to organize global, national, state and district level evidence.

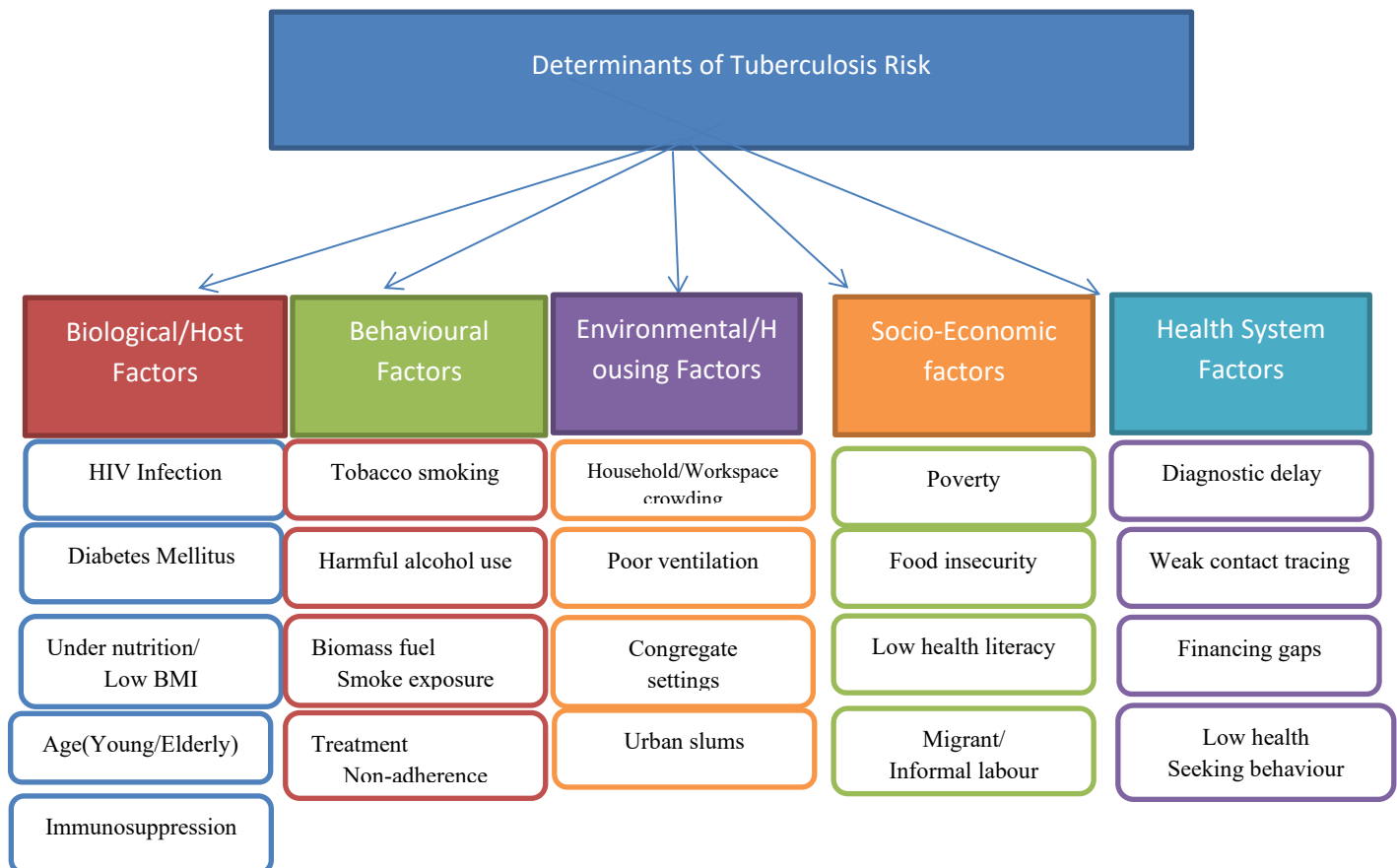


Figure 1. Classification Framework for Global TB Risk Factors Organized into Five Interacting Domains

3.2.1 Biological Host Factors

- HIV infection: It is a major biological risk factor for TB as it significantly increases the risk of progression from LTBI to active TB disease.
- Diabetes Mellitus: It increases the risk of developing active TB and may also be associated with poor treatment outcome.
- Under nutrition/Low BMI: It can weaken cell mediated immunity and increase the risk of developing TB.
- Age: very Young children and older people are at greater risk of TB because their immune system may be less effective and controlling TB infection [7].
- Other Immunosuppressive conditions: Conditions such as cancer treatment, organ transplantation and kidney disease requiring dialysis can weaken the immune system and increase the risk of TB [7].

3.2.2 Behavioural Factors

- Tobacco smoking: It can damage natural defence mechanisms of lungs and increases the risk of TB and mortality.
- Harmful alcohol use: it can weaken immune function and may contribute to poor adherence to TB treatment.
- Indoor air pollution: long term exposure to indoor air pollution from biomass fuels can damage the respiratory system and increase susceptibility to TB.
- Treatment non-adherence and irregular follow-up: Failure to follow the prescribed Treatment and irregular follow-up can increase the risk of treatment failure, relapse and development of drug-resistant TB.

3.2.3 Environmental Housing Factors

- Household and workplace overcrowding: Overcrowded homes and workplaces increase the close and prolonged contact with people who may have TB infection.
- Poor Ventilation: Poorly ventilated indoor spaces allow infectious airborne particles to remain in the air for long periods and cause the risk of TB.
- Congregate settings: Places such as prisons, shelters and dormitories may increase TB transmission because of high occupancy, close contact and inadequate ventilation.
- Urban slums and informal settlements: Overcrowded living conditions, poor sanitation and limited access to health care can increase the risk of TB transmission and delayed diagnosis.

3.2.4 Socio Economic Factors

- Poverty: It can limit the access to adequate nutrition, safe housing and timely healthcare thereby increasing vulnerability to TB.
- Food insecurity and chronic malnutrition: It can contribute to undernutrition which may weaken immunity and increase the risk of TB.
- Low literacy and limited health awareness: Limited awareness of TB symptoms can delay the identification of TB disease and timely healthcare seeking.
- Migrant and informal labours: These factors may experience unstable housing, interrupted healthcare and occupational exposures which can increase their vulnerability to TB.

3.2.5 Health system Factors

- Diagnostic delay: Limited access to rapid molecular diagnostic tests can delay the diagnosis and treatment of TB. According to WHO [1] only 54% of newly diagnosed TB patient globally received a WHO recommended rapid diagnostic test as the initial diagnostic test.
- Weak surveillance and contact tracing system: Weak disease surveillance and inadequate contact tracing can reduce the identification of people who have been exposed to TB and Limit access to preventive measures.
- Drug supply and financing gaps: Insufficient funding and interruptions in the supply of TB medicines can affect the continuity and quality of TB diagnosis and treatment services. WHO 2025 reported that global TB funding remained well below the required annual target [1].

- Low health seeking behaviour: stigma, treatment cost, lack of awareness and distance from healthcare facilities may discourage people from seeking timely diagnosis and treatment for TB.

3.3 Pathogenesis Pathway: From Exposure to Transmission

Figure 2 traces the biological and the epidemiological pathway through which risk factors can lead to exposure to infection, through establishment of latent infection to progression to active TB which may further spread the disease to others.

Onward community transmission perpetuates the epidemic cycle

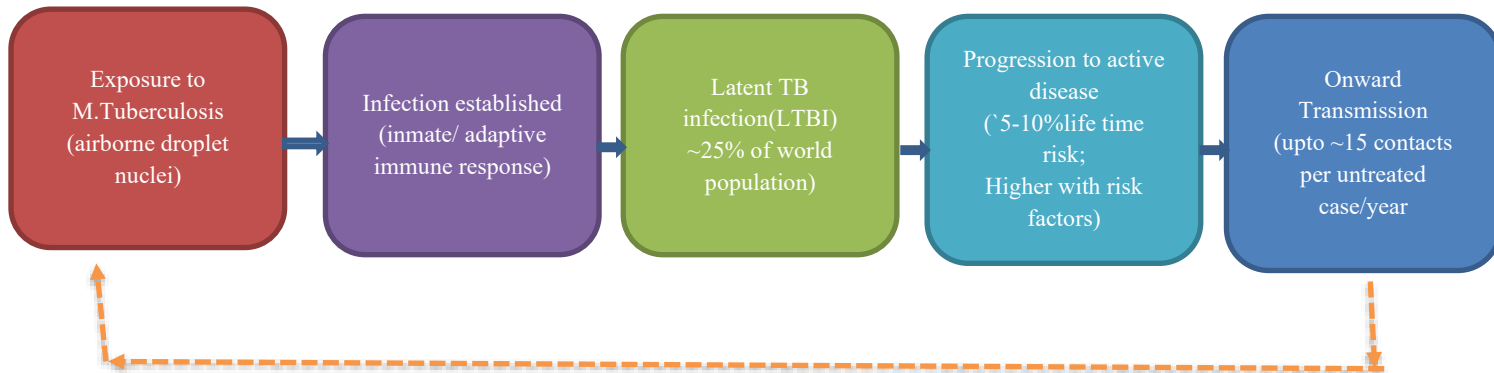


Figure 2. Pathway from TB exposure to active disease and onward transmission.

This pathway clarifies why interventions must act at multiple points simultaneously: reducing exposure through infection control and case finding, preventing progression from infection to disease through TB preventive treatment for high risk contacts and shortening the infectious period through early diagnosis and effective treatment.

3.4 Overlapping Biological Risk Factors

Undernutrition, diabetes mellitus and HIV infection frequently co-occur within the same individuals and communities and each independently impairs immune containment of TB. They overlap the risk of progression from latent to active TB compounds substantially as illustrated in Figure 3.

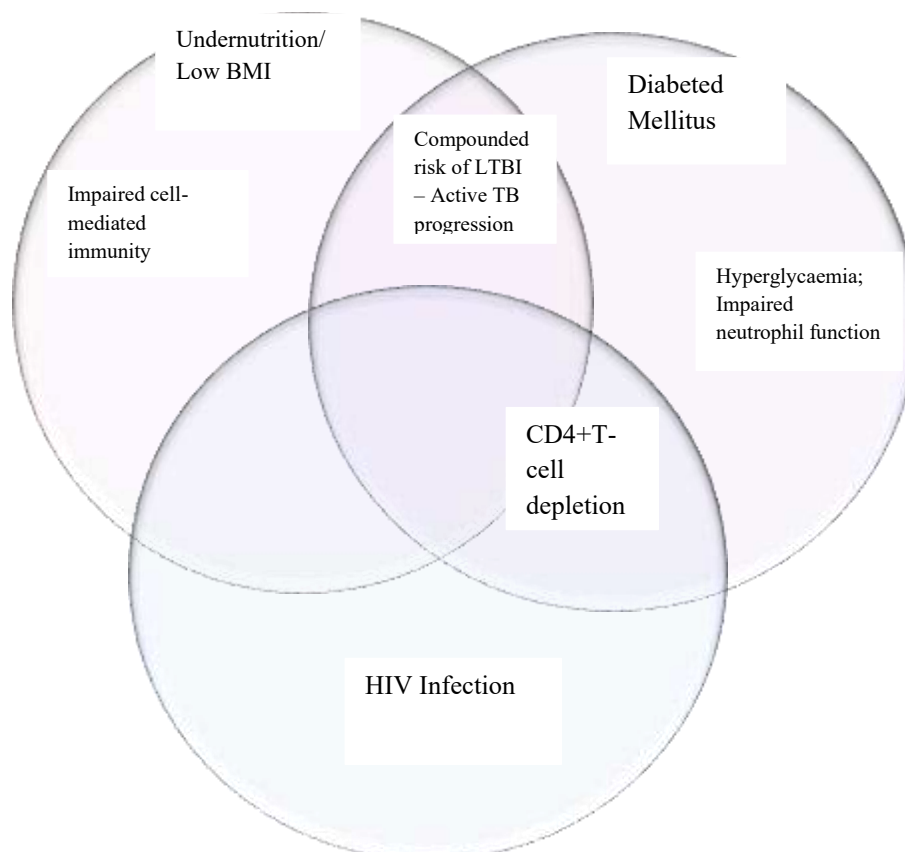


Figure 3 Compounding effect of overlapping biological risk factors driving progression from latent to active TB.

This overlap has direct programme implications. TB programmes are increasingly integrated with diabetes screening, HIV testing and antiretroviral therapy linkage. This also integrated with nutrition support such as India's Nikshay Mitra community nutrition support scheme. Because addressing any one risk factor in isolation leaves the compounding effect of the other unaddressed factors.

3.5 TB Burden in India: National Context

India carries the world's largest TB burden accounting about one-quarter of global incident TB cases (WHO, 2025). To address this burden the Government of India implements the National TB Elimination Programme (NTEP) through the Central TB Division of the Ministry of Health and Family Welfare, proving an integrated framework for TB diagnosis, treatment, prevention and surveillance. The Nikshay digital platform facilitates systematic case notification and patient monitoring nationwide.

India's second National TB Prevalence Survey (2019-2021) found considerable variation in TB prevalence and infection burden across states. TB infection prevalence exceeds 30% in states including Delhi, Telangana, Uttar Pradesh, Punjab, Chandigarh and Karnataka indicating a need to priorities control measures in these regions. At the national level, TB infection prevalence was estimated at 21.7% among males and 19.7 % among females, increasing with age and peaking among individuals aged 45-54 years. According to the survey report it has been estimated about 29%. The annual risk of TB infection was higher in urban areas approximately 2.2% compared with rural areas which is approximately 1.3% [8]. It shows that overcrowded living conditions, slum settlements and higher rate of migrant populations in cities.

Community level studies from across India broadly support these national and International patterns. Studies from Tamil Nadu identifies older age, male sex, low BMI diabetes and previous TB history and alcohol consumption as important factors associated with pulmonary TB [11]. Research from Odisha and Madhya Pradesh further indicates that tribal and rural communities experience a greater TB burden particularly because of limited access to healthcare services [12], [13].

3.6 TB Risk Factor Profile: Punjab State

Punjab is among the Indian states with TB infection prevalence exceeding 30% placing it in a higher priority category for TB elimination Programme nationally. Community based prevalence surveys from Punjab, including from SAS Nagar District have provided important comparative data on TB burden relative to other Indian states.

3.6.1 State level Risk factor Consideration

- Noncommunicable disease burden: Punjab's state wide STEPS survey found a background prevalence of diabetes/hyperglycaemia of 14.3% among adults, hypertension of 40.1% and obesity of 12.8%. All of these factors are epidemiologically relevant because diabetes is strongly associated with increased TB risk.
- Tobacco and alcohol use: Use of tobacco and alcohol among adult men in Punjab remain a significant behavioural determinant of TB risk in Punjab broadly consistent with the global evidence base.
- Agrarian and Industrial Economy: Punjab's mixed agrarian-industrial economy attracts migrant labourers and support substantial industrial and informal sector employment. Workers in these settings frequently live in shared or overcrowded accommodation create a greater chance for TB transmission.
- Urban-Rural Gradient: Urban areas of Punjab experiences greater TB infection risk than rural areas, reflecting higher population density, overcrowding and congregate living and working environments

3.7 District profile: Kapurthala

Kapurthala district headquarter at Kapurthala town is one of the smaller districts in Punjab by both area and population. It is organized into Kapurthala, Sultanpur Lodhi, Bholath and Phagwara sub divisions. It comprises 688 inhabited villages and 6 towns organised into five Community development Blocks such as Kapurthala,, Nadala, Sultanpur lodhi, Dhillwan a nd Phagwara [4].

3.7.1 Key Demographic and Socio-economic Indicators

Table 1. Kapurthala district indicators and their relevance to TB risk (Sources: Census of India 2011, District Census Handbook, Kapurthala; MSME Industrial Profile, Kapurthala).

Indicator	Value	Relevance to TB Risk
Total population (Census 2011)	815,168	Moderate-sized district; enables focused, resource-efficient TB Elimination Interventions
Rural population share	~65.3%	Rural populations nationally show lower annual infection risk but often face diagnostic access delay
Urban population share	~34.7%	Urban pockets, Phagwara and Kapurthala town carry higher density transmission risk
Literacy rate	~80-85%	Higher literacy supports awareness but area of lower literacy delay healthcare seeking
Sex ratio	~912-931 females/1000 males	Gender gaps in health seeking may affect female case detection rates
Scheduled Caste population share	~33.94%	Historically associated with lower socio-economic status and healthcare access barriers
Population density	~501person/sq.km	Moderate density with localised overcrowding in urban wards and industrial worker housing
Industrial base	4305+MSE units; large units including Rail Coach Factory, textile and sugar mills(phagwara belt)	Industrial/informal workforce housing and occupational dust exposure are recognized TB risk contexts

3.8 Key Risk Factors Specific to Kapurthala District

Applying the five-domain of global framework (Section 3.2) to Kapurthala's local context yields the following district specific risk factor assessment. In the absence of a published district level TB prevalence survey specific to Kapurthala this assessment draws on Punjab state level TB and health survey data, national TB programme patterns and kapurthala's documented socio-demographic and industrial profile, it should therefore be read as an evidence informed inference rather than directly measured local finding.

3.8.1 Biological/Host Factors

- Diabetes and related metabolic risk reflecting the broader high-ground prevalence of hyperglycaemia and obesity documented across Punjab. Elevates progression risk from latent to active TB among older adults in the district [1], [6].
- Undernutrition in lower income group such as rural and Scheduled Caste households remains a possible contributor. As given in the Table1 the district includes 33.9% of schedule Caste population and the established association between poor nutritional status and TB [6].
- Age related vulnerability among the elderly rural population may cause to increase TB risk because of delay in seeking healthcare facilities.

3.8.2 Behavioural Factors

- Alcohol and tobacco use among working age men in both agricultural and industrial workers.
- Continued use of biomass and other solid fuels for cooking in some rural areas of Kapurthala may contribute to indoor air pollution and increased respiratory health risk [17].

3.8.3 Environmental and Housing Factors

- Shared and rented housing among migrant and low income industrial labour in the Phagwara industrial belt is a major drive force of household overcrowding.
- Dormitory and labour colony type of housing near large industrial units such as textile mills, sugar mills and the Rail coach factory can be a reason for close contact.
- Village level housing density across the district's 688 inhabited villages where joint family types of arrangements are very common.

3.8.4 Socio Economic Factors

- Seasonal migration of agricultural labourers may create challenges in maintaining uninterrupted TB treatment, monitoring and follow-up [3], [17].
- Economic disparity between the more industrially developed Phagwara tehsil and the more agrarian Kapurthala and Sulthanpur Lodhi tehsils creates deferential to diagnostic and treatment services.
- The simultaneous outward movement of settled families abroad and the inward movement of migrant labourers for agricultural and industrial activities may alter local household structures. It may create additional challenges for TB surveillance, contact identification and continuity of care.

3.8.5 Health System Factors

- Dependence on higher level tertiary healthcare facilities in Jalandhar for the management of complicated TB cases may create additional challenges in ensuring timely diagnosis, treatment and specialist care.
- Geographic variation in the distribution and accessibility of Basic Management Units and microscopy and molecular diagnostic facilities across rural blocks including Nadala, Dhilwan and Sultanpur Lodhi compared with urban areas such as Kapurthala and Phagwara may influence timely access to TB diagnosis and care.
- Reliance on the completeness of TB notification through the Nikshay system may pose challenges particularly for case diagnosed and managed within the expanding private healthcare sector.

•

4. Comparative Risk-Factor Priority Assessment

The following table is an illustrative evidence comparison of relative risk factor priority like Low/ Medium / High across the three levels of geography covered in this report. It is indented as a planning aid to guide where Kapurthala district authorities might focus limited resources relative to global and state pattern. It should also be validated against local surveillance data where available.

Table 2. Comparative risk factor priority matrix: Global Vs Punjab state Vs Kapurthala District (Illustrative, evidence informed assessment)

Risk factor	Global	Punjab State	Kapurthala District
Undernutrition/low BMI	High	Medium	Medium
Diabetes Mellitus	Medium	High	High
HIV Co Infection	High	Low	Low
Tobacco smoking	Medium	Medium	Medium
Alcohol Use	Medium	Medium	Medium
Indoor air pollution-	Medium	Low	Low
Overcrowded housing	Medium	Medium	Medium
Poverty/Low income	High	Medium	Medium
Migrant & informal labour	Medium	Medium	High
Occupational dust exposure (Industrial Units)	Low	Medium	Medium

Diagnostic/notification delay	Medium	Medium	High
-------------------------------	--------	--------	------

Notable contrasts include a relatively higher illustrative priority for diabetes mellitus and migrant/informal labour risk at the kapurthala district level, reflecting its documented industrial-agrarian labour mix and a lower relative priority for HIV co-infection compared to the global picture. This is consistent with India's generally lower adult HIV prevalence relative to high TB-HIV burden regions such as parts of sub-Saharan Africa.

4.1 Priority Risk factors Summary

The following table consolidates the highest-priority risk factors identifies at each geographic level, alongside a suggested primary intervention entry point.

Table 3. Highest priority risk factors identified at each geographical level with suggested primary intervention entry points

Level	Top Priority Risk Factors	Suggested Primary Intervention
Global	Undernutrition; HIV co-infection;diabetes; diagnostic delay	Integrated nutrition, HIV and diabetes linked TB screening;expanded rapid molecular diagnostics
Punjab(State)	Diabetes/metabolic risk, urban overcrowding, tobacco& alcohol use.	State- wide NCD- TB bidirectional screening; urban slum active case finding drives.
Kapurthala(District)	Diabetes/metabolic risk; migrant & informal labour; industrial worker housing density.	Workplace and labour –colony screening in Phagwara belt; migrant-linked treatment continuity support via Nik-shay.

5. Discussion

This review demonstrate that TB risk in Kapurthala district cannot be understood using the global risk factor profile alone. Undernutrition and HIV co-infection dominate the global risk landscape. The evidence assembled here that within Kapurthala's specific socio-economic and industrial context, diabetes/metabolic risk, migrant and informal labour and industrial worker's housing density emerge as the risk factors of greatest local relevance. This pattern is consistent with India's broader epidemiological transition. The burden of non-communicable disease risk factors is increasingly superimposed on a persistent communicable disease burden.

The comparative matrix (Table 2) also highlights a relatively less priority of HIV co-infection at the Punjab and Kapurthala levels. Compared with the global picture reflecting India's lower adult HIV prevalence. This does not indicate that HIV-TB screening and linkage are unimportant locally, but that at the margin. Diabetes linked screening and housing/occupational interventions may offer a higher yield for the district's specific epidemiological profile.

The consistent finding that urban areas carry a higher annual risk of TB infection than rural areas. Both nationally and inference within Kapurthala suggests that active case finding resources should be weighted toward urban and semi-urban industrial clusters.

These findings should be interpreted in light of the review's inferential approach. In the absence of a Kaprthala's specific TB prevalence survey the district level risk assessment presented here is an evidence informed extrapolation from Punjab state and national data. These facts are combined with the district's documented socio-demographic and industrial profile rather than a directly measured local findings.

6. Recommendation for Kapurthala District

6.1 Screening and case-finding

- Institute bidirectional diabetes- TB screening at all Community Health Centres across the district's five blocks, prioritising Phagwara and urban Kapurthala given documented metabolic risk pattern.
- Conduct targeted active case-finding drives in industrial worker housing colonies and labour settlements around the Phagwara industrial belt.
- Strengthen contact tracing and TB Preventive Treatment (TPT) coverage for household contacts of notified cases especially in joint family rural households.

6.2 Addressing Structural and Behavioural Risk

- Link eligible TB patients and at-risk households to nutritional support schemes like Nikshay Mitra to address undernutrition among lower income and Scheduled Caste households.
- Integrate tobacco and alcohol cessation counselling into TB treatment and follow-up visits.
- Promote improved ventilation cooking solutions in rural blocks still reliant on biomass fuel.

6.3 Health-System Strengthening

- Expand access to rapid molecular diagnostic testing at Basic Management Units in the more rural blocks such as Nadala, Dhillwan and Sultanpur Lodhi to reduce diagnostic delay relative to urban areas like Kapurthala and Phagwara.
- Improve private sector TB notification completeness through Nikshay outreach, given the district's growing private healthcare footprint.
- Establish migrant worker TB treatment continuity protocol, given seasonal agricultural and industrial labour mobility in and out of the district.

7. Limitations

- This is a narrative review rather than a systematic review. The literature search was not exhaustive or pre-registered. Some relevant local studies may not have been identified.
- No dedicated, published TB prevalence survey exists for Kapurthala district. All district-specific conclusions are inferential extrapolation from Punjab state level and National data combined with the district's demographic and industrial profile.
- The comparative priority matrix (Table 2) is an illustrative, expert judgement based ranking rather than statistically derived or weighted index. It should be treated as planning heuristic rather than a measured risk score.
- Several state-level surveys like STEPS survey estimates were collected some years prior to this review. So it may not fully reflect current prevalence given secular trends in diabetes and obesity in Punjab.

8. Conclusion

Tuberculosis prevalence is influenced by a complex interplay of biological, socio-economic, environmental and health system related risk factors that vary across geographical levels. At the global level undernutrition, HIV infection, diabetes, tobacco smoking and alcohol use continue to represent major modifiable determinants of TB. Poverty and deficiencies in health care access further increase vulnerability. In Punjab, the combination of substantial background burden of TB infection and a growing noncommunicable disease burden highlights diabetes and urban overcrowding as important areas for intervention. At the district level, Kapurthala presents a distinctive risk environment due to its mixed agrarian-industrial economy, migrant and informal workforce and moderate rural housing density.

Consequently, strengthening diabetes-linked TB screening, improving living conditions for industrial and informal workers. Similarly ensuring continuity of TB care among migrant populations should form important components of local TB control strategies. However, in the absence of a dedicated district level TB prevalence survey, locally generated surveillance data are required to validate these assumptions and guide evidence based prioritisation.

References

1. World Health Organization. (2025). Global Tuberculosis Report 2025. Geneva: WHO.
2. India Tuberculosis Report, 2023, <https://www.data.gov.in/catalog/india-tuberculosis-report-2023>

3. Central TB Division, Ministry of Health and Family Welfare, Government of India, ICMR–National Institute for Research in Tuberculosis. (2022). National TB Prevalence Survey in India (2019–2021): A technical report.
4. Census of India. (2011). District Census Handbook – Kapurthala, Punjab. Directorate of Census Operations, Punjab.
5. Kaur, P., Rao, S. R., et al. Prevalence of TB infection in India: Findings from analysis relevant to Punjab and comparable North Indian settings. ScienceDirect [Indian Journal of Tuberculosis / related], 2023 analysis.
6. Thakur & Nangia, (2022), Prevalence, Awareness, Treatment, and Control of Hypertension and Diabetes: Results from Two State-Wide STEPS Survey in Punjab and Haryana, India, *Frontiers in Public Health / PMC*. <https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2022.768471/full>
7. Selvaraju et al., (2023), Prevalence and factors associated with tuberculosis infection in India, *Journal of Infection and Public Health*. <https://www.sciencedirect.com/science/article/pii/S1876034123003362>
8. National Family Health Survey (NFHS-5), 2019–21. State Fact Sheet: Punjab. Ministry of Health and Family Welfare, Government of India.
9. Prevalence, Awareness, Treatment, and Control of Hypertension and Diabetes: Results from Two State-Wide STEPS Surveys in Punjab and Haryana, India. *Frontiers in Public Health / PMC*.
10. Profile of Risk Factors for Non-Communicable Diseases in Punjab, Northern India: Results of a State-Wide STEPS Survey. *PLOS ONE*.
11. Srinivasan et al., 2021, Prevalence of bacteriologically confirmed pulmonary tuberculosis and associated risk factors: A community survey in Thiruvallur District, south India, *PLoS One*. <https://pmc.ncbi.nlm.nih.gov/articles/PMC8491886>
12. Hussain et al., 2020, Prevalence, risk factors and health seeking behaviour of pulmonary tuberculosis in four tribal dominated districts of Odisha: Comparison with studies in other regions of India. *PLoS One*. <https://pmc.ncbi.nlm.nih.gov/articles/PMC7135306>
13. Rao et al., 2018. A comparative study of the socio-economic risk factors for pulmonary tuberculosis in the Saharia tribe of Madhya Pradesh, India, *PubMed*. <https://pubmed.ncbi.nlm.nih.gov/29931208/>
14. Centers for Disease Control and Prevention. Signs and Symptoms of Tuberculosis. Atlanta: Centers for Disease Control and Prevention; 2025.
15. Brief Industrial Profile of Kapurthala District, Punjab. <https://www.dcsmse.gov.in/dips/Kapurthala.pdf>
16. Jessy Juian ,Sudhakar Ranjan,Roopali Sood., Development of a Predictive Model for Tuberculosis (TB) in a Small Town Like Kapurthala, Punjab Using AI, *International Journal of Computer Information Systems and Industrial Management Applications*ISSN 2150-7988 Volume 18(23s) 2026 pp. 179-190 Scopus Indexed DOI: <https://doi.org/10.70917/ijcisim-2026-5563>
17. Jessy Julian, Sudhakar Ranjan, Artificial Intelligence in Tuberculosis Control in India: A Review (2025), *International Journal of Novel Research and Development* 10(10), DOI:10.56975/ijnrd.v10i10.309808.https://www.researchgate.net/publication/398879484_Artificial_Intelligence_in_Tuberculosis_Control_in_India_A_Review
18. Jessy Julian, Sudhakar Ranjan, Uncovering the Causes of Tuberculosis in Small Towns and Villages of Punjab: Socio-Environmental and Health Determinants(2025), *Advanced International Journal for Research* 6(6), DOI:10.63363/aijfr.2025.v06i06.2413. <https://www.researchgate.net/publication/399109211>
19. Jessy Julian, Sudhakar Ranjan, Bridging the Diagnostic Divide: AI-Enabled Tuberculosis Detection across Rural and Small Urban Centres of Punjab, *International Journal of Research Publication and Reviews*, Vol 7, Issue 5, pp 5678-5684 May, 2026, DOI : <https://doi.org/10.55248/gengpi.07.0526.a1236> <https://ijrpr.com/uploads/V7ISSUE5/IJRPR65089.pdf>
20. S. Ranjan, A. Barthwal and M. Uddin, "A Comparative Analysis of Machine Learning and CNN-GNU Models for Early Detection of Breast Cancer," 2025 IEEE DELCON - International Conference on Recent Smart Technologies in Engineering for Sustainable Development, New Delhi, India, 2025, pp. 1-5, doi: 10.1109/DELCON68055.2025.11399859.

21. A. Barthwal, S. Ranjan and S. Avikal, "Cardiovascular Disease Analysis and Diagnosis Using Machine Learning Models," 2024 2nd International Conference on Advancements and Key Challenges in Green Energy and Computing (AKGEC), Ghaziabad, India, 2024, pp. 1-6, doi: 10.1109/AKGEC62572.2024.10868066.
22. P. Vasisht, S. Ranjan, R. J. Jadhav, P. R. Rasal and N. K. Nrip, "Artificial Intelligence as a Driver of Industrial Competitiveness," 2022 International Conference on Smart and Sustainable Technologies in Energy and Power Sectors (SSTEPS), Mahendragarh, India, 2022, pp. 210-213, doi: 10.1109/SSTEPS57475.2022.00060.