DISSERTATION TRAINING

at

PATH

A REPORT ON

"A Comprehensive Review of Tuberculosis Care Cascade in India: Disease Burden, Gaps, Role of Government and Digital Health Interventions"

By

Kanya Verma

PG/24/045

Under the guidance of

Dr. Sumesh Kumar

Post Graduate Diploma in Hospital and Health Management

2024-2026

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TO WHOMSOEVER IT MAY CONCERN

This is to certify that **Kanya Verma** student of PGDM (Hospital & Health Management) from International Institute of Health Management Research, New Delhi, has undergone internship training at PATH From 11 March, 2026 to 10 June, 2026. The Candidate has successfully carried out the project designated to him during internship training, and his/her approach to the study has been sincere, scientific, and analytical. The Internship is in fulfillment of the course requirements.

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Abbreviation

ABDM	Ayushman Bharat Digital Mission
AI	Artificial Intelligence
ART	Anti-Retroviral Therapy
BCG	Bacillus Calmette-Guérin (vaccine)
CBNAAT	Cartridge-Based Nucleic Acid Amplification Test
DALYs	Disability-Adjusted Life Years
DBT	Direct Benefit Transfer
DOTS	Directly Observed Treatment, Short-course
DR-TB	Drug-Resistant Tuberculosis
DS-TB	Drug-Sensitive Tuberculosis
DST	Drug Susceptibility Testing
GBD	Global Burden of Disease
GeneXpert	Gene Expert (Xpert MTB/RIF molecular diagnostic test)
HIV/AIDS	Human Immunodeficiency Virus / Acquired Immunodeficiency Syndrome
ICMR	Indian Council of Medical Research
IHME	Institute for Health Metrics and Evaluation
IIT	Indian Institute of Technology
LTBI	Latent Tuberculosis Infection
MDR-TB	Multi-Drug Resistant Tuberculosis
MoHFW	Ministry of Health and Family Welfare
NIDAAN	Integrated Lung Health Screening and Tuberculosis Detection through AI at National Scale
NHA	National Health Authority
NTEP	National Tuberculosis Elimination Programme
NSP	National Strategic Plan
PBCT	Pulmonary Bacteriologically Confirmed Tuberculosis
PLHIV / PLWH	People Living with HIV / People Living with HIV
RR-TB	Rifampicin-Resistant Tuberculosis
RNTCP	Revised National Tuberculosis Control Programme
SDG	Sustainable Development Goal
TB	Tuberculosis
TPT	Tuberculosis Preventive Treatment
UNAIDS	Joint United Nations Programme on HIV/AIDS
USAID	United States Agency for International Development
WHO	World Health Organization
XDR-TB	Extensively Drug-Resistant Tuberculosis

Abstract

Background: Tuberculosis (TB) remains a major public health challenge in India, which accounts for nearly one-quarter of the global TB burden and the highest number of drug-resistant TB cases. Despite significant progress under the National Tuberculosis Elimination Programme (NTEP), substantial gaps persist across the TB care cascade, delaying India's progress toward TB elimination. This review assesses the current TB burden, identifies gaps in the care continuum, and evaluates the role of government initiatives and digital health interventions in strengthening TB control.

Methods: A descriptive review using secondary data and published literature was conducted over approximately 100 days. Data were obtained from the WHO Global TB Reports, NTEP reports, Global Burden of Disease database, PubMed, Scopus, Google Scholar, and peer-reviewed literature published from 2015 onwards. The analysis focused on TB burden, state-wise disease indicators, care cascade gaps, government programmes, and digital health interventions in India.

Results: India recorded over 12.21 million TB-related DALYs in 2023, with marked interstate disparities. Although TB incidence declined from 248 to 195 per lakh population and mortality from 27 to 21 per lakh between 2015 and 2022, both remained considerably above national targets. In 2023, 2.55 million TB cases were notified, with 95% treatment initiation and 87% treatment success among drug-sensitive TB patients. However, substantial attrition persisted across the TB care cascade, including delayed diagnosis, underdiagnosis, treatment interruption, and inadequate preventive therapy. Household contact investigation showed 92% screening coverage, yet only 24% of eligible contacts received tuberculosis preventive treatment (TPT)**.** Comorbidities such as diabetes, HIV, tobacco use, and alcohol consumption continued to adversely affect treatment outcomes. Digital health initiatives including Nikshay**,** AI-enabled chest X-ray interpretation (qXR, DeepCXR, NIDAAN), and AI-based adverse outcome prediction models demonstrated promising potential to improve early diagnosis, treatment monitoring, and patient outcomes.

Conclusion: India has achieved notable improvements in TB case detection, treatment coverage, and digital innovation; however, persistent gaps across the TB care cascade continue to impede elimination efforts. Strengthening active case finding, universal drug susceptibility testing, preventive therapy, integrated management of comorbidities, public-private collaboration, and AI-enabled digital health solutions will be essential to accelerate progress toward the WHO End TB Strategy and India's goal of TB elimination.

Keywords: Tuberculosis, TB care cascade, India, National Tuberculosis Elimination Programme, Digital Health, Artificial Intelligence, Nikshay, TB burden, Drug-resistant TB, Public Health.

Background

TB Burden and India's Progress

Tuberculosis continues to impose a staggering global burden — in 2024, nearly 10.7 million new cases were recorded alongside 1.23 million deaths, reflecting an incidence rate of 131 per 100,000 population and a case fatality rate of 11.5%.[1] While India shoulders roughly a quarter of all TB cases worldwide, it has simultaneously demonstrated one of the steepest rates of decline among countries with a high disease burden.[1]

Between 2015 and 2024, India's TB mortality rate dropped from 28 to 21 deaths per lakh population, [1-2] and treatment coverage surged from 53% to an impressive 92% over the same period. Even so, India still contributed to approximately 28% of TB-related deaths globally in 2024.[1] Despite achieving the fastest reduction in TB incidence anywhere in the world — a 21% drop over the decade from 2015 to 2024 — the country fell short of its self-set elimination target for 2025.[2-3] The WHO Global TB Report 2025 reaffirms that India carries the world's heaviest TB burden, responsible for 25% of global cases and a troubling 32% of all drug-resistant TB (DR-TB) cases.[1] The National TB Elimination Programme (NTEP) has made meaningful strides in case notification and treatment coverage, yet persistent gaps remain in reaching high-risk groups and curbing mortality.[3] Meeting the Sustainable Development Goal of ending TB will require India to accelerate its annual decline in TB mortality from the current 22 per lakh to just 3.2 per lakh population.[4] Achieving this will necessitate differentiated, patient-centric approaches specifically targeting vulnerable populations.[4-5]

Causes of TB

TB is a contagious disease that is caused by a bacterium called Mycobacterium tuberculosis. It is airborne when infected people cough, sneeze or spit. In the process the bacterium is carried in tiny droplets and transmitted to other people who inhale these droplets. People who carry the bacterium but are not experiencing a active infection can not transmit TB to others. While TB is both preventable and treatable, delayed or absent treatment can prove fatal. Standard management relies on antibiotic therapy.[6]

In many countries, the BCG vaccine is routinely administered to newborns and young children as a preventive measure. Although its efficacy is particularly strong against extrapulmonary forms of the disease, it remains a vital tool in early protection against TB.[6,7]

Symptoms of TB

Latent TB infection (LTBI) produces no noticeable symptoms and cannot be passed from person to person. Only a fraction of those with LTBI go on to develop active disease — a risk that is notably higher among young children and infants.

Common symptoms of active TB include:

- A persistent cough, which may produce blood
- General weakness and fatigue
- Fever
- Night sweats

- Chest pain

The specific symptoms experienced depend largely on which organ or system the TB bacteria have affected.

Several conditions are known to heighten the risk of progression from latent to active TB:

- Diabetes mellitus
- Malnutrition
- Tobacco use
- A compromised immune system, such as that seen in HIV/AIDS

Once TB becomes active, symptoms may initially be subtle and slow to develop, yet the disease can be unknowingly transmitted to others during this period. Combating TB remains one of India's most pressing public health challenges, given the country's disproportionately high disease burden. Despite substantial national efforts, TB continues to threaten the health and livelihoods of millions. A thorough reassessment of current evidence — spanning epidemiology, gaps in the care cascade, and the socioeconomic dimensions of the disease — is essential to understanding why the 2025 elimination target proved elusive.[6-7]

Chapter 1 Introduction

In 2022, TB claimed 1.3 million lives, including approximately 167,000 deaths among people living with HIV. This makes TB the second deadliest infectious disease in the world, trailing only COVID-19 and surpassing HIV/AIDS. That same year, around 10.6 million people developed TB globally — among them 5.8 million men, 3.5 million women, and 1.3 million children. TB spares no demographic; it crosses all age groups and national boundaries, yet remains both preventable and treatable.

Drug-resistant TB, particularly MDR-TB, represents a compounding public health emergency. As of 2022, treatment coverage for drug-resistant TB stood at only around 40% globally. On a more encouraging note, coordinated global efforts since the year 2000 are estimated to have saved approximately 75 million lives. Realising the ambitions set at the 2018 UN High-Level Meeting on TB will require annual investment of $13 billion across prevention, screening, diagnosis, treatment, and care. Ending the TB epidemic by 2030 remains an explicit target within the United Nations Sustainable Development Goals.[7]

India accounts for 25% of the global TB burden, recording an estimated 2.6 million new cases and nearly 450,000 deaths annually. The disease disproportionately strikes the most marginalized sections of society — those living in poverty, in overcrowded conditions, or with weakened immune systems, including people living with HIV. Adding further complexity to the epidemiological picture, India also registers the highest number of MDR-TB cases of any country in the world.[7]

India's healthcare system has been engaged in this fight for decades. The Revised National TB Control Programme (RNTCP), launched in 1997 and subsequently restructured as the NTEP, has been instrumental in expanding diagnostic and treatment services nationwide. The incorporation of advanced diagnostic tools such as GeneXpert and Line Probe Assay, alongside the expansion of DOTS centres to support treatment adherence, has been central to these efforts. Nevertheless, significant gaps persist. A large share of the TB burden is managed within the private healthcare sector, where diagnostic and treatment standards remain inconsistent. Meanwhile, the public health system contends with documentation challenges and chronic overload, contributing to delays in both diagnosis and treatment initiation. Addressing these structural shortcomings is fundamental to more effective TB control.8]

Beyond its health implications, TB carries a heavy socioeconomic toll in India. The disease predominantly strikes people during their most economically productive years, imposing financial strain on affected households and the broader economy alike. Direct costs include diagnosis and medication expenses, while indirect costs — loss of income, travel, and lasting disability — compound the burden further.9] Among households affected by TB in India, nearly 32% face catastrophic levels of treatment-related expenditure.[10]

Social stigma further deepens this burden, often driving patient isolation, discrimination, and deteriorating mental health. Tackling stigma through sustained public awareness campaigns and active community engagement is essential for improving treatment adherence and alleviating the social consequences of the disease..[11]

India's TB control efforts face multiple simultaneous challenges. The high prevalence of MDR-TB is particularly concerning, given that treatment regimens for drug-resistant disease are

longer, more costly, and more toxic. Infrastructure deficits and shortages of skilled health workers — especially in rural and remote regions — further limit access to quality care.[12] Comorbidities such as diabetes and HIV add another layer of complexity to patient management.[6]

Underreporting and underdiagnosis remain critical obstacles. Despite advances in diagnostic capability, the often asymptomatic nature of early-stage TB, combined with limited public awareness, means a substantial proportion of cases go undetected. Strengthening surveillance and active case-finding strategies is essential to closing this gap.[8]

Yet amid these challenges, genuine opportunities exist. The government's strong political commitment — including a national goal to eliminate TB by 2025, five years ahead of the global target — has translated into meaningful policy support and funding. Emerging technologies such as digital chest radiography and next-generation sequencing hold significant promise for improving case detection and drug resistance surveillance.[13]

Applying a care cascade model — as has been done in HIV management — allows for the systematic tracking of patients across the continuum of care, revealing where gaps in retention occur and enabling targeted quality improvements. Without a clear understanding of the challenges at each stage of the TB care pathway, meaningful reform cannot be achieved.[14-15]

Those sharing a home with a pulmonary TB patient face an elevated risk of infection owing to sustained proximity to an infectious source.[16] Household contact investigation is therefore a cornerstone of TB control strategy, with an emphasis on early detection and swift action to interrupt transmission. Screening all household contacts for LTBI and providing appropriate preventive therapy can substantially reduce the overall burden of TB by severing the chain of transmission.[17]

LTBI among household contacts is acquired through close, sustained contact with an active pulmonary TB patient — most commonly a family member. Research suggests that within one year of a household index case being diagnosed, 75% of exposed contacts become infected, rising to 97% within two yearsThe molecular epidemiological investigations show that cumulative risk of infection at one, two and five years is 45, 62 and 83% respectively.14In clinical practice, one limitation is the unavailability of validated biomarkers to differentiate between an incident and old latent infection; hence first ruling out active disease by effective means is essential before starting TPT in high risk individuals.[19-20]

All these factors go in line with WHO End TB strategy aiming at 90% TPT coverage among people with HIV and contacts with TB patients by 2025.21] Scaling up household-level TPT implementation is expected to meaningfully reduce the risk of TB transmission and contribute to lowering the broader disease burden.[20-21]

India bears the world's largest TB epidemic, contributing roughly 23–27% of global TB cases and "missing" cases[22]. In 2022 India notified 2.42 million TB cases (27% of global cases), slightly above the 2019 count (2.40 million)[23]. The national incidence has fallen from 256 per 10000 in 2015 to 210/100,000 in 2021[23]. Aggressive case-finding (22 crore people screened in 2021) and expanded diagnostics have driven record notifications. Importantly, WHO-estimated TB deaths in India dropped sharply from ~494,000 in 2021 to 331,000 in 2022

(27% of global TB mortality) after revised data from India's Sample Registration System. However, TB still exacts a heavy burden in health-adjusted terms: in 2019 TB caused about 1,810 DALYs per 100,000 population (about 3.5% of India's total DALYs). (DALYs combine years of life lost and years lived with disability to reflect overall disease impact[26].
India's TB incidence (~199/100,000 by 2023) far exceeds the NSP 2025 target (≤44/100k,000

The gap between estimated prevalence and reported cases remains large: ~2.8 million Indians had TB in 2022 vs only 2.42 million notified[. This "missing cases" gap has nearly doubled since 2019, underscoring under-diagnosis[27]. The TB care cascade demonstrates the attrition from the point of illness to a cure. For the public system in India, based on 2013 data, out of approximately 2.7 million prevalent cases of TB, only 72% reached a public TB clinic, and only 60% were ever diagnosed. Of these, only 53% were initiated on treatment, 45% were treated to completion and only 39% reached the ideal outcome (1 year relapse free survival). In essence, about 1 out of 3 TB patients were lost at each step of the cascade. It has been noted in a systematic review that millions of Indian individuals with active TB are never diagnosed or notified[22].Systemic gaps have been shown to exist at many levels: patients failing to seek treatment or being overlooked at each stage, symptoms presenting at the clinic but failing to be investigated or correctly diagnosed [29], and a large proportion of diagnosed patients not receiving adequate treatment and dropping out[22]. Cascade results are even worse in retreatment cases and cases with drug resistant TB[22].

The burden of disease is further quantified not only by the number of cases and deaths, but also by Disability-Adjusted Life Years (DALYs), which measure years of life lost to disability as well as mortality, and by systemic failures in delivering care from diagnosis and screening through to adherence and follow up. Recent years have seen the adoption of digital health interventions such as electronic reporting and tracking, mobile-based adherence reminders and treatments, and AI-powered diagnostics. However, conclusive evidence demonstrating the value of digital health solutions to bridge care delivery gaps are not yet available. The aim of this study is to present a comprehensive review of the burden of TB in India, discuss gaps in the care cascade and scope of digital health solutions.

Research Aim

1. To assess the tuberculosis burden in India, identify gaps across the TB care cascade, and evaluate the role of government initiatives and digital health integration in improving TB care delivery and patient outcomes.

Primary Objective

1. To assess gaps across the tuberculosis care cascade in India and evaluate the role of government initiatives and digital health interventions in strengthening TB care delivery.

Secondary Objectives

1. To analyze the current burden of tuberculosis in India, including state-wise prevalence, mortality, and Disability-Adjusted Life Years (DALYs).
2. To identify challenges and gaps across different stages of the TB care cascade, including screening, diagnosis, treatment initiation, adherence, follow-up, and outcome monitoring.
3. To examine existing government-led TB control programs and digital health interventions and explore opportunities for strengthening TB management through digital health integration.

Chapter-2 Rationale of the Study

India carries the world's largest TB burden, accounting almost 25% of world cases, India is still behind in its targets for TB elimination. Despite significant advances in case notification and treatment coverage, there is a large gap between estimates and notifications of TB cases, with over 2.8 million estimated prevalent cases and 2.42 million reported cases for 2022 alone, illustrating an enormous degree of missed cases and underdiagnosis of TB disease. The TB care cascade in India demonstrates a striking attrition at every stage: out of an estimated 2.7 million prevalent cases in India, just 39% eventually resulted in treatment success, with losses observed at every step of screening, diagnosis, treatment initiation, adherence, and follow up.[5] There is an even higher attrition rate in cases with drug-resistance and retreatment cases. Besides death, TB poses a significant disability burden in India, causing roughly 1,810 DALYs per 100,000 people, indicating its significant impact on daily functioning. Although government programs like the NTEP have been successful in increasing the reach of diagnostic tools and treatments, persistent structural issues like uneven private sector management, infrastructure limitations, lack of proper reporting, and the role of social stigma continue to thwart efficient control. Newer approaches in digital health, like Nikshay, AI diagnostic technologies, and mobile adherence support, are showing promise in closing gaps in care delivery, but robust evidence for these innovations remains elusive. This systematic review aims to provide an extensive map of TB burden in India, highlight the key gaps in the TB care cascade, and assess the impact of the country's initiatives and digital health solutions in improving TB service delivery toward elimination.

Chapter -3 Review of Literature

3.1 Health System and Patient-Level Barriers in Tuberculosis Care

Gargi Thakur, Shalvi Thakur, and Harshad Thakur (2020) conducted a qualitative study of healthcare providers, policymakers, patients, and public health officials, which highlighted health system barriers, including weak infrastructure and poor follow-up of positive screens, as well as patient barriers such as poor adherence, stigmatization, and a lack of awareness. These barriers affect case finding, treatment compliance and thus, control of TB. The authors concluded that both strengthening the healthcare system and raising community awareness were required to combat TB.

In a qualitative literature review by Harsh D. Shah, Mahalaqua Nazli Khatib, Zahiruddin Quazi Syed, Abhay M. Gaidhane et al. (2022) revealed that delayed care-seeking by patients, insufficient diagnostic infrastructure, and stigma remain major obstacles that interfere with the prompt identification and effective management of tuberculosis. Patient awareness, community participation, and improvement in diagnostic facilities need to be ensured to enhance TB management services.

3.2 Household Contact Screening and Tuberculosis Preventive Treatment

The screening of household contacts for tuberculosis is essential for early diagnosis and prevention of the disease. According to a prospective cohort study by Banurekha Velayutham, Lavanya Jayabal, Basilea Watson et al. (2020) in urban Chennai using a structured contact screening card, TB screening rates among household contacts significantly improved and stigma, lack of time and a false sense of wellbeing were the major factors inhibiting contacts'

participation in screening. Follow-up screening at 6 and 12 months further increased the case detection and treatment initiation.

In a study by A.D. Harries, S. Satyanarayana, P. Kumar et al. (2020) concerning the implementation of tuberculosis preventive treatment (TPT) for household contacts of pulmonary TB cases in India, authors stressed the role of preventive therapy in the management of latent TB infection. They identified a weak health system infrastructure, a lack of adherence to prescribed TPT, and socio-economic obstacles among barriers to effective implementation. The need for strengthening TB control by training healthcare workers, community engagement and linking the TB program with existing programs were recommended to enhance TB care.

The impact of missing opportunities for the screening and TPT initiation of household contacts was assessed in a cross-sectional study by P. Thekkur, R. Thiagesan, D. Nair et al. (2023) using various indicators for timing of care and treatment initiation and adherence. The authors recommended an improvement in follow up services of households by strengthening their monitoring and feedback systems.

3.3 Diagnostic Delays and Missed Opportunities in TB Care

Significant delays in diagnosis and initiation of treatment are observed in TB care in India. According to a cross-sectional assessment conducted by Sandul Yasobant, Harsh Shah, Priya Bhavsar et al. (2023) in Jharkhand and Gujarat states of India, barriers to the diagnosis and treatment cascade for tuberculosis included poor awareness, addictions, other diseases and their management, limited diagnostic resources and poor monitoring of adverse effects of anti-tubercular therapy. The same authors also added to poor health seeking behavior being linked to socio-economic factors, myths/ misinformation, the high cost of diagnostics, restricted availability of tests and limited accessibility, which in turn affect the care and treatment of TB in Harsh D. Shah, Shalu Chaudhary, Bharat Desai, Jay Patel et al. (2024).

In a systematic review by Rechel Shrisunder, Manesh Muraleedharan, Sammita Jagdish Jadhav and Dwight Figueiredo (2025) examining 25 out of 253 articles regarding the management and control of tuberculosis cases in India, they classified the missed cases into two major categories- patient-related and provider-related. The factors under the patient related category were; migration, alcoholism, illiteracy, fear of side-effects and depressive thoughts associated with anti-tubercular drugs and the poor records of their health history. Poor communication, faulty sputum collection, inadequate diagnosis support, incorrect identification of TB cases and a lack of Ni-KSHAY notification were the identified provider-related factors.

3.4 Economic Burden and Catastrophic Costs of TB

The financial burden associated with the treatment of tuberculosis can hinder access to and completion of care. Susmita Chatterjee, Palash Das, Guy Stallworthy, Gayatri Bhambure et al. (2024) explored the financial burden encountered by TB patients in India using mixed methods research and survey data, investigating both direct and indirect costs incurred by patients and highlighting the influence of various methodologies in the estimation of catastrophic costs. The authors also pointed out the need to standardize the methods used for estimating cost and to strengthen the social protection elements within tuberculosis programs.

3.5 Latent TB Infection and Preventive Treatment Implementation

Latent TB infection (LTBI) is a significant factor in TB elimination and it is important to implement the preventive treatment of latent TB infection among household contacts of patients with active disease to curb the progression of the disease from LTBI to active TB infection. Literature and policy documents onLTBI by Hashim, Zia; Tyagi, Richa; Singh, Gajendra Vikram; Nath, Alok; and Kant, Surya (2024) demonstrated the usefulness of LTBI preventive treatment, but lack of patient adherence, weak healthcare facilities and limited implementation capacity posed barriers. Success of preventive treatment has been shown in highrisk population.

Analysis of program data among 133,167 notified pulmonary TB cases in Maharashtra India by Anuj Mundra, Tarun Bhatnagar, Mrinalini Das, Sandeep Sangale, Hemant Patil, Abhishek Raut, Aniruddha Kadu, Rameshwar J. Paradkar, Subodh S. Gupta and Bishan S. Garg (2026) revealed that contact tracing was done for 84% of TB cases while TB symptoms were screened for 95% of 406,291 enrolled contacts. The authors reported that TPT was initiated in 55% of all eligible contacts and only 41% of TPT initiators were cured by the end of the treatment. Lost opportunities occur at every step in the TPT cascade and the authors recommended data reporting, service decentralization, capacity building, monitoring, and supportive supervision for the same.

3.6 TB Care Cascade among People Living with HIV

People living with HIV are at high risk of developing TB and systematic screening and preventive therapy are crucial for their care. In the study on the implementation of the TB care cascade among adult PLWH registered in ART centres in Odisha, India by Asmita Patnaik, Tarun Bhatnagar, Mrinalini Das, D. S. Arvind, Prabodh Kumar Siya, Arghya Pradhan, Prasanta Kumar Hota, Bikash Patnaik, Subrat Kumar Panda, Subhakanta Sahu, Hrushikesh Das, Sneha Pattanayak and Arvind Kumar Singh (2026) out of 4835 newly enrolled PLWH only 19.3% had data for 4S TB screening and of these screened individuals 94.3% were screened and 18.4% reported to have symptoms ofTB. Of those tested for LTBI only 64.2% had their LTBI preventive treatment initiated. The findings highlight the gaps in reporting of clinical history for symptoms and in initiating and treating latent TB among PLWH**.**The reviewed literature shows that TB control in India is affected by delays in diagnosis, poor treatment adherence, missed cases, incomplete contact tracing, weak preventive treatment implementation, and socio-economic barriers. While several studies have explored patient-level and provider-level challenges, recent evidence highlights major gaps in the TB preventive treatment cascade, especially among household contacts and high-risk groups such as PLHIV. There is a need for stronger documentation systems, decentralized screening, improved follow-up mechanisms, healthcare worker training, and community engagement to reduce missed opportunities in TB prevention and care.

Chapter – 4 Research Methodology

Study Design –
Descriptive analysis of tuberculosis (TB) indicators along with comprehensive Literature Review, to assess gaps across the TB care cascade in India.
Study Methodology
Study Approach
The framework of analysis will focus on:

1. TB disease burden in India
2. State-wise TB indicators and DALYs
3. Gaps across the TB care continuum
4. Government-led TB control initiatives
5. Existing digital health interventions in TB care
6. Opportunities for strengthening TB services through digital integration

Data Sources- Secondary data and literature will be collected from :

- Government Reports NTEP (TB Report)
- Global Burden of Disease (GBD) database
- Scientific Databases
- PubMed
- Scopus
- Google Scholar
- Peer-reviewed journal articles

Duration of the Study
Over a period of approximately **100 days**
Data Collection Method
Secondary data collection using quantitative and qualitative data related to TB burden, care cascade indicators, government interventions, and digital health technologies will be extracted from published reports, databases, and literature.
Inclusion Criteria

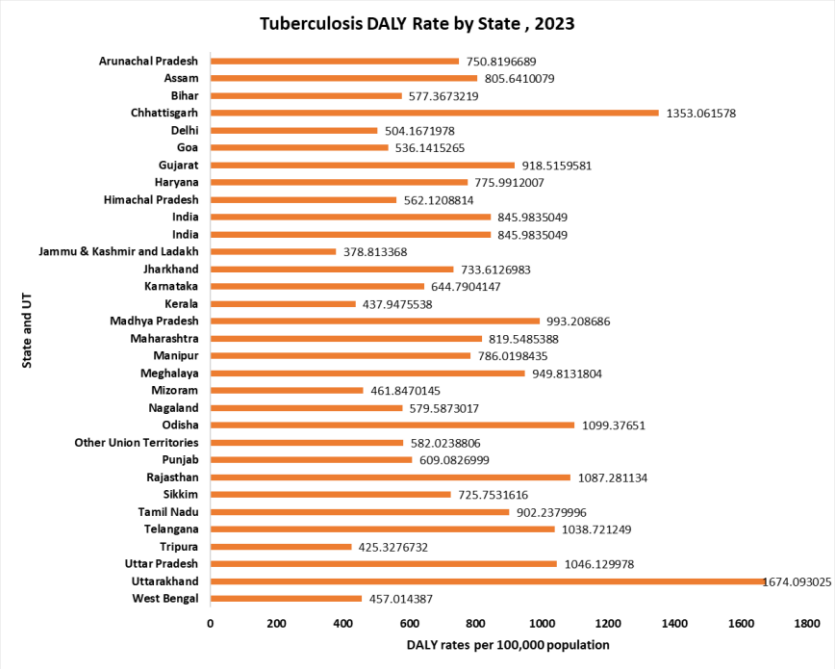
1. Studies and reports related to tuberculosis in India
2. Literature published in English
3. Government publications and peer-reviewed studies
4. Studies discussing TB care cascade gaps and digital health interventions
5. Publications from 2015 onwards

Exclusion Criteria

1. Non-India-specific studies without relevant contextual findings
2. Editorials and opinion-based articles lacking evidence
3. Duplicate studies
4. Studies unrelated to TB care continuum or digital health integration

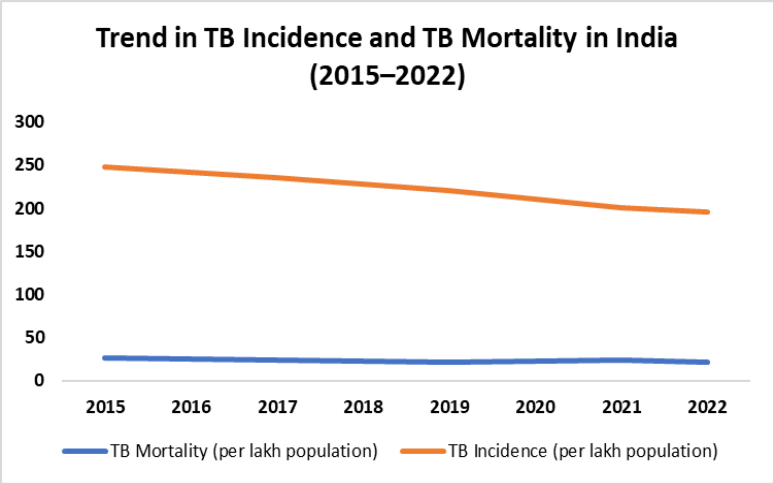
Data Analysis Tool
Microsoft Excel for descriptive statistical analysis and graphical representation

Chapter – 5 Results



Graph 5.1 TB DALYs rate per 100,00 population across states, 2021. Source – IHME GBD 2023

Graph 5.1 shows that in 2023, India experienced a significant health loss, where tuberculosis contributed to about 12.21million DAL Ys. This made up 2.52% of the entire disease burden at a rate of 845.98 DALYs per 100,000 population across the country. There was variability between states as states had different levels of burden from tuberculosis. In absolute terms, Uttar Pradesh suffered from the highest burden (2.72 million DALYs) compared to any other state, followed by Maharashtra (1.04 million DALYs), Madhya Pradesh (0.93 million DALYs) and Rajasthan (0.93 million DALYs). Together, these three states constitute a considerable part of the country's total burden from tuberculosis. In terms of per 100,000 of population, Uttarakhand showed the highest burden (1674.09 per 100,000), followed by Chhattisgarh (1353.06 per 100,000), Odisha (1099.38 per 100,000), Rajasthan (1087.28 per 100,000) and Uttar Pradesh (1046.13 per 100,000). These states are affected disproportionately more by tuberculosis per capita than the other states, where Jammu & Kashmir (378.81 per 100,000), Kerala (437.95 per 100,000) and West Bengal (457.01 per 100,000) had relatively fewer DALYs per 100,000 from tuberculosis. These observations highlight that tuberculosis burden remains high in India but is spread unevenly across states, indicating a necessity of targetinspecific states in their efforts to reduce premature mortality and disability from this disease.



Graph 5.2 Tuberculosis incidence and mortality in India (2015-2022) Source – India TB Report 2024

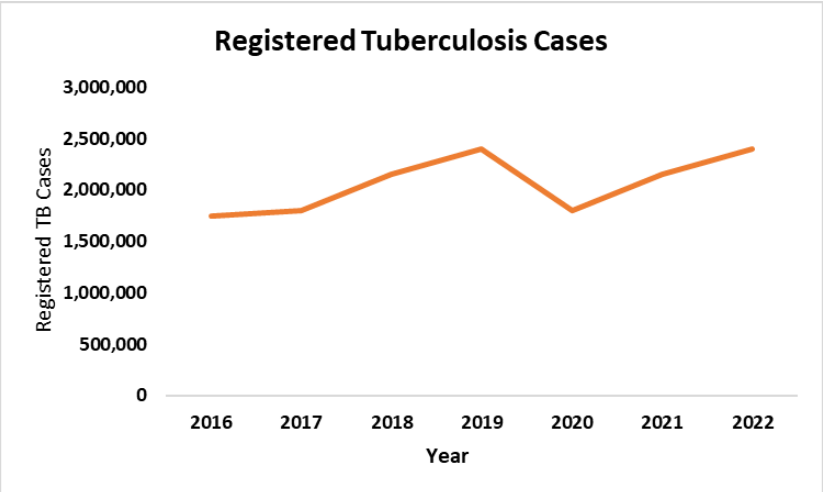
Graph 5.2 reveals the slow decrease in the burden of tuberculosis in India during 2015 to 2022, with cases falling from 248 to 195 per lakh population and mortality from 27 to 21 deaths per lakh population respectively. The steady downward trend from 2015 to 2019 shows effective prevention, diagnosis and treatment services. A temporary spike in mortality during 2020-2021 can be attributed to disruptions in the services due to the Covid 19 pandemic but in 2022, rates improved with a decrease in incidence and mortality. Still the incidence and mortality continue to be at high levels and therefore, there is a need for intensification of control measures to meet the objectives of National TB Elimination Program and WHO End TB strategy.

S. No.	Indicator	Baseline (2015)	Target (2023)	Achievement (2023)
Impact Indicators				
1	Estimated TB incidence rate (per lakh population)	217 (112–355)	77 (49–185)	199
2	Estimated TB mortality rate (per lakh population)	32 (29–35)	6 (5–7)	23
3	Households facing catastrophic costs due to TB	35%	0%	NA
Outcome Indicators				
4	Total TB patient notifications (million)	1.74	2.70	2.55
5	Notifications from private healthcare providers (million)	0.19	1.50	0.84
6	MDR/RR-TB patients notified	28,096	69,000	63,939
7	Notified TB patients offered drug susceptibility testing (DST)	25%	98%	58%
8	Notified TB patients initiated	90%	95%	95%

	on treatment			
9	Treatment success rate among notified DS-TB patients	75%	92%	87%
10	Treatment success rate among notified DR-TB patients	46%	73%	65%
11	Targeted key affected populations undergoing active case finding	0%	100%	NA
12	Notified TB patients receiving financial support through DBT	0%	90%	70%

Table 5.1 Progress Towards Tuberculosis Elimination in India: Comparison of Baseline (2015), National Strategic Plan Targets (2023), and Achievements (2023) Across Key Impact and Outcome Indicators. ***Source – India TB Report 2024***

The findings for India's TB report 2024, demonstrate substantial progress in India's TB control efforts, particularly in increasing case notifications, treatment initiation, MDR/RR-TB detection, and financial support coverage. However, despite these improvements, the country remained considerably short of the ambitious targets set under the National Strategic Plan and the WHO End TB Strategy. By 2023, TB incidence (199 per lakh) and mortality (23 per lakh) remained far above the target levels of 77 and 6 per lakh population, respectively. These gaps indicate that while India has accelerated progress towards TB elimination, the pace of decline was insufficient to achieve the national goal of eliminating TB by 2025, highlighting the need for intensified efforts in early detection, universal drug susceptibility testing, treatment success, and preventive interventions.



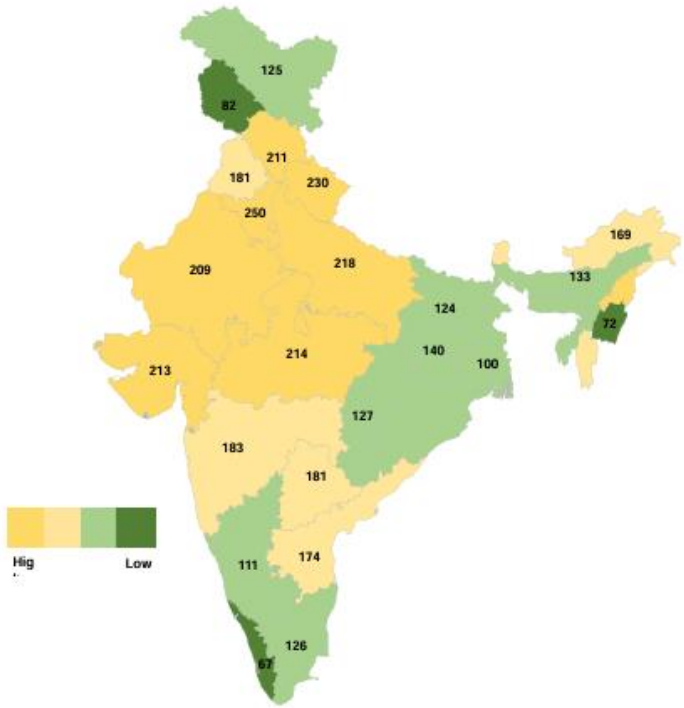
Graph 5.3 Year-wise Registered Tuberculosis Cases in India, 2016–2022. Source – India TB Report 2024

The registered cases of tuberculosis (TB) in India between the years 2016 and 2022 are shown in Graph 5.3. Between 2016 and 2019, there was a consistent rise in the number of registered cases of TB, from about 1.75 million to 2.4 million, reflecting the enhanced reporting of TB patients. The year 2020 recorded a steep decline to approximately 1.8 million cases of TB; the COVID-19 pandemic had a negative impact on TB screening, diagnosis, and reporting, and it likely affected reported case notifications in that year. Case registrations then picked up after 2020, rising to about 2.15 million cases in 2021 and peaking at 2.4 million cases in 2022. This indicates that TB services are restored and case detection is on an upward trajectory, and it emphasizes the role that NTEP continues to play in case finding activities. The downturn of reported cases in 2020 emphasizes the critical nature of TB case finding and other TB control

efforts in health emergencies.

In 2023, India notified 2.55 million cases of tuberculosis (TB). This achieved 92.4% of the target notification (2.76 million cases). The TB notification rate in the entire country was 178.8/lakh population and 1.71 million (93.5%) and 0.84 million (90.1%) notifications came from the public and private sector respectively.

These data confirm the excellent performance in terms of detection and reporting under NTEP, while also confirming the lag in case notification as against the estimate.



Graph 5.4 TB case notification rate across India 2022. Source – India TB Report 2024

In 2022, India recorded an all-time high of 2.42 million TB cases with a national TB notification rate of 172 cases/100,000 population, a 13% increase from 2021. It was also observed that 95.5% of TB patients notified were initiated on treatment, indicating a huge success of the National TB Elimination Programme (NTEP) in linking the diagnosed TB patients to treatment.

State wise TB Notification rates:

It was observed that the TB notification rates were diverse across states and union territories of India and varied between various regions based on several factors like disease burden, access to healthcare facilities, effectiveness of surveillance system, and case finding. Delhi recorded highest number of TB notification cases (507.2/100,000 population), suggesting a considerable burden of disease and a strong case finding system. The states with the second and third highest TB notification rates were Chandigarh (556.4/100,000 population) and Puducherry (263.5/100,000 population) respectively. It is important to be noted that Haryana and Uttar Pradesh followed close by recording 260.8 and 260.1 cases/100,000 population respectively. High notification rate in these regions may not necessarily be just a marker of high burden of

disease, but also of efficient disease surveillance and case identification system.

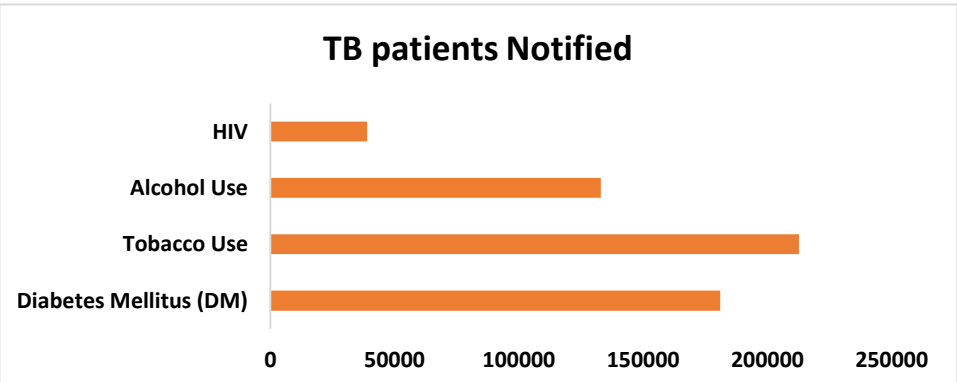
There are some states that recorded moderate numbers of notification cases that are also considerably higher than others including Uttarakhand (220.9/100,000 population), Madhya Pradesh (209.0/100,000 population), Sikkim (206.4/100,000 population), Nagaland (204.1/100,000 population) and Rajasthan (203.8/100,000 population). It is of note that although the number of cases being detected is high in these regions due to effective programmatic approach but the burden is still present and requires considerable attention to control the spread of TB.

On the contrary, Lakshadweep registered lowest notification rate of 9/100,000 population. This was followed by Kerala (61.5/100,000 population), Manipur (69.4/100,000 population) and Jammu & Kashmir (77.6/100,000 population) which recorded a considerably lower rate compared to the national average and other states. These low notification rates may also mean lesser burden of the disease in those regions, efficient public health interventions, and a good reporting mechanism.

Regional Disparities:

The presence of stark regional differences in TB notification rates implies uneven distribution of the burden of TB and unequal outcomes from TB control program across the states of India. Regions with higher TB burden, such as Delhi, Uttar Pradesh, Haryana, and Madhya Pradesh, require greater attention on intensifying active case finding, early diagnosis, and ensuring treatment adherence so as to reduce transmission in the community. Regions with lower notification rates like Kerala and Jammu & Kashmir might have certain lessons to learn from other regions in terms of prevention strategies and public health system efficiency; on the other hand the highly affected regions must follow their strategies to tackle the TB burden. A comprehensive, statespecific approach must be employed to combat with the varied levels of TB prevalence across India and thereby achieve the goal of eradicating TB from India.

Out of 2.36 million TB patients notified across India in 2022, a total of 87.6% of them had a successful treatment outcome. The mortality rate was 3.6%, amounting to more than 85,000 deaths, whereas loss to follow up and treatment failure accounted for 2.0 and 0.5% respectively. Andhra Pradesh, Telangana, Gujarat and Sikkim achieved successful treatment outcome above 90% whereas states of Delhi, Goa and Manipur showed comparatively low successful treatment outcome percentage. While a lot has been achieved, continuous effort on improving the death and loss to follow up cases is needed to reach the goal of ending TB.



Graph 5.4 TB case notification among comorbids. Source – India TB Report 2024

Fig. 5.4 indicates the significant comorbidities and risk factors in TB patients in India and importance of integrated care approaches in the National TB Elimination Programme (NTEP). Diabetes mellitus is one of the leading comorbidities impacting TB outcomes. By 2023, among the notified TB patients 92.5% had a known diabetes status and 181026 patients (7.7%) were TB-diabetes co-infected. However, only 112858 (62.3%) of them were initiated on anti-diabetic treatment. Diabetes itself is a leading risk factor for TB through the impairment of immune responses and is associated with delayed sputum conversion, treatment failure, relapse, and mortality. Tobacco use, continues to be a critical behavioral risk factor for TB. Among notified TB patients, 75.0% were known to have tobacco use status and 212658 TB patients (11.1%) were identified as tobacco users. Only 67304 patients (31.6%) among them were referred to tobacco cessation centers. Respiratory diseases caused by smoking impairs immunity and increases the risk of acquiring TB. In addition it is associated with delayed TB outcomes, recurrence of illness and mortality. Likewise, 73.6% of the TB patients were screened for alcohol use and 132966 (7.1%) TB patients were identified as alcohol users. Only 44574 patients (33.5%) among them were referred to de-addiction centers. Alcohol overuse, further compromises immunity and makes treatment interruption more common, resulting in higher mortality. The intersection of TB with HIV is another significant area for concern. HIV is one of the strongest risk factors for the development of active TB because HIV severely compromises immunity, expedites the progression from dormant TB infection to active TB and remains the commonest opportunistic infection in PLHIV causing significant mortality. The continued high burden of HIV-TB co-infection needs strengthening of the collaborative TB-HIV activities, including routine HIV testing in all TB patients, early initiation of ART, and coordinated care. The programme has focused on antenatal screening among pregnant women as well. Between 2023, out of the total female patients with TB, 647440 (64.7%) was screened for pregnancy and 3430 patients were identified as pregnant TB patients (0.5%). Early detection of pregnancy associated TB, will prevent detrimental outcomes for both the pregnant woman and the foetus and will ensure early initiation of treatment and prompt management.

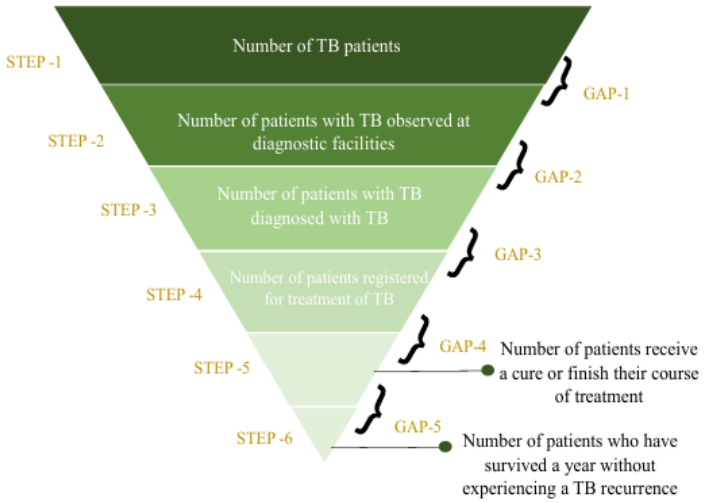


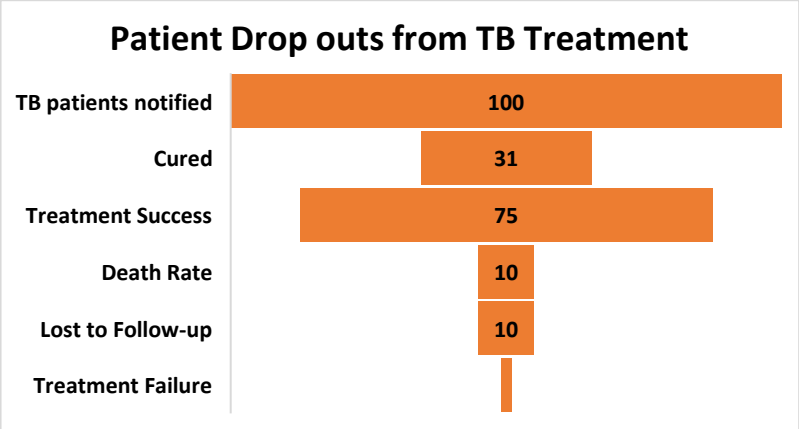
Figure 5.1 Steps of the TB care cascade and gaps across each steps. Source – India TB Report 2024

Figure 5.1 shows that the TB care cascade in India has major gaps. At each step of care there is attrition among patients, resulting from various factors related to individuals, society and health system. Patients are often unaware of early symptoms of TB, and this delays access to

healthcare. Even with early symptomatic presentation, access to diagnostics services is restricted due to long distances to travel, problems with transport, inability to afford costs, loss of wages. In some cases, the individuals that have reached the health facility are not properly screened for TB, or referred for diagnosis, or missed or delayed diagnoses occur. Even following diagnosis several barriers affect the patients from starting treatment or completing treatment course. Social stigma, poverty, lack of family support, lost or delayed diagnoses and treatments all contribute to the patient attrition across the continuum of care. Some patients either have severe illness that can lead to deaths before treatments are initiated. Such losses necessitate improving patient-centered care, access to diagnostics and treatment, and follow-up to facilitate continuity of care, to ensure improvement in treatment outcomes and acceleration toward TB elimination in India. Table 5.1 shows treatment care cascade among notified TB patients in India, 2022 and also demonstrates significant variations between public and private sectors of health in terms of outcomes achieved. A total number of 2,082,444 patients were notified of TB in 2022 in India, and bulk of them were notified by public health system (1,527,464; 73.3%) compared to private healthcare sector (554,980; 26.7%). Treatment outcomes achieved indicate successful treatment outcome in 1,779,602 patients; thus giving overall treatment success of 85.5%. Treatment success achieved between public sector (85.0%) and private sector (86.7%) seems similar; however, a huge discrepancy is seen between cure rate achieved at the public health system (35.8%) and the private sector (5.7%), giving overall cure rate of 27.8%. As in spite of the highest treatment success outcome, a good number of patients had adverse outcomes; 88,060 patients died during treatment, thus having an overall mortality of 4.2% in the treatment group, compared to the public (4.5%) and private (3.6%) sectors. Loss to follow up was 54,127 (2.6%) and a relatively higher percentage was observed at the private health facilities (3.4%) compared to the public health facilities (2.3%). Loss to treatment was seen among 11,308 patients (0.5%), which was also slightly higher among patients under public health system (0.6%) compared to the private sector (0.4%). This suggest that despite having a high treatment success among the notified cases, the country needs to improve more on mortality and loss to follow up rates by strengthening the treatment adherence support and better linkages with the public and private sectors of health.

Indicator	Public (n)	Public (%)	Private (n)	Private (%)	Total (n)	Total (%)
TB Patients Notified	1,527,464	–	554,980	–	2,082,444	–
Cure Rate	547,544	35.8	31,494	5.7	579,038	27.8
Treatment Success Rate	1,298,240	85.0	481,362	86.7	1,779,602	85.5
Death Rate	67,985	4.5	20,075	3.6	88,060	4.2
Lost to Follow-up	35,222	2.3	18,905	3.4	54,127	2.6
Treatment Failure Rate	9,259	0.6	2,049	0.4	11,308	0.5

Table 5.2 TB related indicators , Source – India TB Report 2024



Graph 5.5 Patient dropout rates from each step of treatment , Source – India TB Report 2024

The TB care cascade is a visual tool to assess how many people with active TB are followed along the TB care continuum. The cascade defines the key steps taken through the processes of diagnosis, treatment, and follow-up, and the gaps between steps show the proportion of patients lost to care or who fail to reach the subsequent stage. These gaps are defined by the discrepancy in numbers from one step to the next in the continuum.

There are five key gaps that can be identified along the care cascade. Gap 1 represents individuals with active TB disease who do not attend a health facility for medical care or to receive a diagnosis. Gap 2 is those individuals who attend a facility for care and/or diagnosis but are not diagnosed as having active TB. Gap 3 comprises those individuals who are diagnosed but do not initiate treatment or register on treatment. Gap 4 comprises those individuals who are registered for treatment and do not achieve treatment success, as they may die, be lost to follow-up, fail treatment or for other reasons. Gap 5 is those individuals who achieve treatment success but relapse or die within 12 months after completion of therapy (Fig. 5.1).

The care cascade model is one that is well-utilized in global health programs, as it can pinpoint where weak links exist in the continuum of care and track success of efforts to reach control goals. Other well-established care cascade models were instrumental in assessing public health programs,

including the UNAIDS 90-90-90 goals for HIV by outlining areas in which patients may be

lost along the care pathway and focusing interventions where needed.

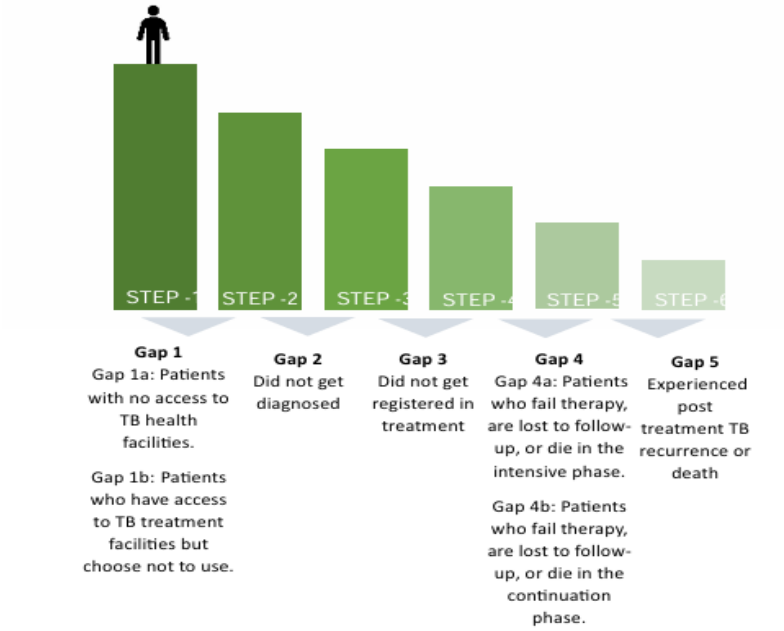


Figure 5.2 Gaps in the TB care cascade in india in each steps. Source – India TB Report 2024

State	No. of HHC of PBCT	Screened for TB (%)	Symptomatic for TB (%)	Evaluated for TB (%)	Diagnosed with TB (%)	Put on TB Treatment (%)	Provided TPT* (%)
India	3,356,272	92	2	71	41	72	24
Uttar Pradesh	845,733	94	1	39	74	80	11
Rajasthan	250,376	94	1	58	40	51	40
Maharashtra	230,636	93	3	82	36	92	22
Madhya Pradesh	221,772	88	1	70	56	60	37
West Bengal	203,273	95	1	66	20	50	51
Gujarat	173,593	96	3	84	12	79	36
Bihar	132,398	89	1	46	77	77	19

Note: *TPT = Tuberculosis Preventive Treatment provided after ruling out active TB cases.*
Table 5.3 State-wise HHC Screening and Treatment Outcomes for Pulmonary Bacteriologically Confirmed TB Patients (PBCT) in India, 2022. Source – India TB Report 2024

Table 5.3 demonstrates that there was indeed significant progress in household contact investigation and TPT coverage for pulmonary bacteriologically confirmed TB (PBCT) patients in India in the year 2022. 92% of the 3.36 million detected contacts of household contacts of PBCT cases were screened for TB in 2022. 71% of investigated household contacts were evaluated for TB, and 72% of identified TB cases were started on anti- TB treatment. However, 24% of eligible household contacts were started on Tuberculosis Preventive Treatment (TPT) after ruling out active TB.

Care Cascade Gap	Current Situation	Key Challenges	Recommended Interventions
Gap 1: TB Testing and Case Detection	Approximately **68% of the estimated 2.84 million incident TB cases** undergo TB testing.	• Limited awareness of TB symptoms among the general population. • Low healthcare-seeking behaviour .• Inadequate access to quality-assured diagnostic services, particularly in remote and underserved areas.	• Implement targeted public awareness campaigns on TB symptoms and early diagnosis. • Strengthen community engagement through local leaders, civil society organizations, and health workers. • Expand access to quality-assured diagnostic services in underserved regions.
Gap 2: TB Diagnosis	Only **57% of the estimated incident TB cases** are successfully diagnosed.	• Limited availability of quality diagnostic facilities. • Poor specimen collection and transportation systems. • Delays in diagnostic testing and reporting of results.	• Strengthen diagnostic infrastructure and laboratory networks .• Scale up rapid molecular diagnostic technologies such as Xpert MTB/RIF. • Improve specimen transport mechanisms and turnaround times. • Provide regular training to healthcare providers on TB diagnostics and interpretation of results.
Gap 3: Linkage to Treatment	Only **50% of estimated TB cases** are initiated on treatment.	• Limited awareness regarding free TB treatment services. • Financial barriers to accessing care. • Weak coordination between public and private healthcare sectors.	• Increase awareness of free TB treatment services under NTEP. • Strengthen financial and social support mechanisms for vulnerable populations .• Enhance referral systems and coordination between public and private providers.
Gap 4: Treatment Completion	Only **43% of estimated TB cases** successfully complete treatment.	• Medication-related adverse effects. • Inadequate social and family support. • Difficulties in accessing treatment	• Strengthen patient counselling and psychosocial support services.• Implement robust treatment adherence monitoring

		services, especially among marginalized populations.	systems. • Improve access to comprehensive care, including management of comorbidities and drug-resistant TB.
Gap 5: Long-Term Recovery and Relapse-Free Survival	Only **37% of estimated TB cases** achieve sustained recovery without recurrence.	• High rates of post-treatment relapse and recurrence. • Inadequate post-treatment follow-up. • Limited access to comprehensive care for patients with comorbidities and drug-resistant TB.	• Establish structured post-treatment follow-up programmes .• Strengthen integrated management of comorbid conditions. • Enhance drug-resistance surveillance and monitoring systems to detect and manage emerging resistance patterns.

Table 5.4 Limitations of present estimations and suggestions for enhancing the situation of India's tuberculosis cascade of care. [41]

Digital Government of India Initiatives to Accelerate Tuberculosis Elimination Through AI and Digital Health

AI has been successfully incorporated into the Indian Government's National TB Elimination Programme (NTEP) to enhance TB screening, diagnosis, treatment monitoring, and outcome prediction. AI technologies were leveraged between 2022-2025 in an effort to combat issues of late diagnosis, shortages of TB specialists and poor treatment outcomes.

AI-based chest X-ray interpretation platforms (DeepCXR and qXR) have been adopted for the detection and triage of presumptive TB. DeepCXR, implemented in 8 Indian States and Union Territories, analyzes digital chest radiograph images for presumptive TB, a crucial method in resource-limited areas with low radiologist availability. Through the IndiaAI Mission, NIDAAN, the "iNtegrated Lung Health Screening and Tuberculosis Detection through AI at National Scale", has further enhanced TB detection, utilizing AI-driven chest X-ray analysis to identify more than 30 pulmonary pathologies.

During the course of TB treatment, AI predictive models have been rolled out nationally to identify patients at high risk for treatment failure, loss to follow-up, and poor treatment outcomes early in the treatment course. The implementation of AI models is reported to have resulted in a 27% reduction in adverse outcomes from TB.

These AI integrations into the TB program are part of the wider national digital health strategy, which includes the IndiaAI Mission, Ayushman Bharat Digital Mission, and creation of a National Federated Learning Platform for the validation of AI models. The use of AI within the national TB program is aligned with ethical practices through ICMR Ethical Guidelines for AI in Healthcare (2023) and National AI Governance mechanisms to protect patient privacy and ensure transparency.

Sector	Initiative/Technology	Organisation	Application	Reported Impact
Public	Adverse Outcome Prediction Model	Ministry of Health & Family Welfare (NTEP)	AI-based predictive analytics for identifying patients at risk of poor treatment outcomes	27% reduction in adverse TB outcomes
Public	DeepCXR	Government of India/NTEP	Automated chest X-ray interpretation for TB triaging and screening	Deployed in 8 States/UTs to support specialist shortages
Public	NIDAAN (IndiaAI Mission)	Government of India	AI-assisted chest X-ray analysis for lung disease and TB detection	Detects and localises 30+ radiological findings
Public	National Federated Learning Platform	NHA & IIT Kanpur	Validation and benchmarking of AI health models under ABDM	Supports development of reliable AI-enabled TB tools
Private	qXR	Qure.ai	AI-powered chest X-ray interpretation for TB detection and screening	Used across 1,000+ sites; improved TB detection by approximately 30%
Private	AI Smart Scans	Qure.ai	Deep-learning analysis of chest X-rays and CT scans for TB and lung diseases	Serves approximately 15 million patients annually
Private	AI-Powered Tele-radiology Platforms	Various private providers	Remote AI-assisted interpretation of TB screening images	Enhanced access to diagnostic services in underserved areas

Table 5.5 GOI India Initiatives to Accelerate Tuberculosis Elimination Through AI and Digital Health [42]

IndiaAI Mission and Its Contribution to Tuberculosis Elimination and Healthcare Innovation

Launch of the IndiaAI Mission in March 2024 represents a significant policy step taken by India to utilize AI for the society and healthcare sector improvement. With financial sanction of INR 10,371.92 crore, this mission was approved by the Union Cabinet with the goal of development, scale-up and deployment of AI solutions addressing issues of national importance such as healthcare delivery. Under the IndiaAI Application Development Initiative, the government is funding creative AI solutions to enhance disease screening, diagnosis and management of disease treatment and improving access to healthcare. Amongst the list of healthcare solutions selected in the IndiaAI Application Development Initiative, the NIDAAN

(iNtegrated Lung Health Screening and Tuberculosis Detection through AI at National Scale) is directly related to elimination of TB. NIDAAN leverages qXR, an advanced AI-powered chest X-ray interpretation tool that can identify and locate >30 pulmonary abnormalities to help in mass scale TB screening and early diagnosis. It will act as a boost to current NTEP practices by improving diagnostic capacity of health facilities lacking radiologists in areas like rural India. Apart from TB, IndiaAI is also supporting the deployment of AI-enabled radiology platforms, diabetic retinopathy screening tools, diagnostic wearable sensors, neuroinformatics tools, AI assisted diabetic eye screening system, virtual AI health assistants and cancer detection tools that are expected to build the digital health sector of India, improve clinical outcomes, reduce health disparities, enhance equitable health access to everyone in the society and achieve the aims of Universal Health Coverage as well as vision of Viksit Bharat by 2047.

Chapter – 6 Discussion

Our analysis concludes that TB still remains as one of the biggest cause of illness and premature death in India, with approximately 12 million plus DALYs in 2023. This aligns with the W.H.O and Institute of Health Metrics and Evaluation (IHME) estimates, which has declared India as the country contributing the highest to the global burden of TB over the past few decades. The significant difference in DALYs between states such as Uttar Pradesh, Rajasthan, Chhattisgarh and Uttarakhand with states like Kerala and Jammu & Kashmir implies that average national rates mask severe disparities among states. Previous studies by Indian researchers on TB burden also have shown similar regional variations due to differences in poverty, under-nutrition, access to healthcare services, population density and health system. The observed decline in incidence and mortality from 2015-23, as estimated in the study are in agreement with the WHO Global TB Reports and National Tuberculosis Elimination Programme (NTEP) which noted slow trends of TB incidence and mortality due to an increase in molecular diagnostics use, active case finding, universal free sensitive treatment regimens, and notification system improvement. However the observed rate of decline is still slower than expected by the W.H.O End TB Strategy and the values for incidence (199/lakh) and mortality (23/lakh) rates for 2023 are still far from India's goals for 2023 as observed by other scholars (Pai et al; Reid et al). The drastic improvement in notifications from 2015 23 by 2.5 million were estimated by Central TB Division and W.H.O due to improvements in surveillance, mandatory notification and involvement of the private sector. While previously the low notifications implied lack of case detection, recent trends are likely to be due to a rise in case finding rather than an increase in TB burden. The drop in notifications in 2020 as seen in our study indicates a considerable disruption in care and an increase in deaths in that year as also reported by Bhargava et al., and Glaziou. There were notable differences in TB treatment success rate between states, 87.6% found in this study is consistent with WHO's values, and better than those reported from other high-burden countries. Telangana, Andhra Pradesh, Gujarat and Sikkim reported high treatment success, possibly due to better case- adherence support and programme implementation. Delhi, Goa and Manipur, however, showed high mortality and low treatment success, which was correlated with migration, delayed treatment presentation and health system weaknesses as reported by Chadha et al. High notifications with high mortality reported from Delhi indicates a need for better patient linkage and support besides identification of cases. The TB care cascade showed loss of cases at each stage but more losses from diagnosis to initiation of treatment, which corresponds to previously observed data from Indian studies by Subbaraman et al. And Arinaminpathy et al., who noted that almost half of incident TB cases are lost from the system before completing the entire treatment regimen, thus highlighting need for improvement at pre-treatment stages. Co morbidities like diabetes, HIV, tobacco and alcohol continue to influence TB treatment outcome and increase

risk of TB progression and mortality, confirming evidence from various studies (Jeon & Murray; Narasimhan et al). Hence, the call for integrated TB treatment models, including those for non-communicable diseases and HIV and substance use services have again been reiterated. The study also highlights emerging roles for Artificial Intelligence (AI) and digital health in the modern paradigm of TB control which will facilitate TB detection and screening more effectively compared to conventional techniques used earlier (qXR, DeepCXR, NIDAAN etc.) as supported by studies demonstrating improved outcomes and reduced risk in these technologies. Thus a move toward precision public health with integrated AI into the National Health Programme of India may prove beneficial in overcoming the TB care cascade bottlenecks. Thus the current study reiterates previous observations on slow but improving TB trends in India; however, considerable gaps exist in diagnostic delays and timely treatment adherence in specific regions of the country. Thus a need for focused efforts toward elimination of TB in India based on integrated biomedical strategies that incorporate health system improvements along with social determinants of health has been emphasized by researchers and the study reinforces such points of argument by providing latest state-level data for TB burden and performance with an additional component of latest technologies for better disease detection and management

Chapter – 7 Conclusion

Tuberculosis continues to pose a major public health challenge in India despite notable progress under the National Tuberculosis Elimination Programme (NTEP). The findings demonstrate that India has achieved substantial improvements in TB case notification, treatment initiation, treatment success, drug-resistant TB detection, and expansion of digital health interventions. National TB incidence and mortality have shown a declining trend since 2015, and treatment success rates have remained high, reflecting strengthened programmatic efforts and improved access to care. However, the burden of disease remains considerable, with TB accounting for over 12.2 million DALYs and exhibiting marked interstate disparities, particularly in high-burden states such as Uttar Pradesh, Rajasthan, Madhya Pradesh, Maharashtra, and Chhattisgarh.

The analysis further highlights persistent gaps across the TB care cascade, including underdiagnosis, delayed treatment initiation, inadequate preventive therapy coverage, and losses during treatment and post-treatment follow-up. While India notified more than 2.5 million TB cases in 2023 and achieved high treatment initiation rates, the country remained substantially short of the National Strategic Plan and WHO End TB Strategy targets. TB incidence and mortality levels were considerably higher than the desired benchmarks, indicating that the pace of progress has been insufficient to achieve the goal of TB elimination by 2025. Comorbidities such as diabetes, HIV infection, tobacco use, and alcohol dependence continue to adversely influence TB outcomes and require stronger integration of TB services with broader health programmes.

Encouragingly, the Government of India has increasingly leveraged artificial intelligence, digital surveillance systems, predictive analytics, telemedicine, and the IndiaAI Mission to strengthen TB screening, diagnosis, treatment monitoring, and outcome prediction. AI-enabled platforms and adverse outcome prediction models demonstrate the potential of digital innovation to improve case detection, optimize patient management, and reduce adverse outcomes. These initiatives signify a transition toward data-driven and precision public health approaches for TB control.[42]

Overall, achieving sustainable TB elimination in India will require intensified efforts in active case finding, universal drug susceptibility testing, preventive therapy expansion, integrated management of comorbidities, patient-centred support systems, and strengthened public-private collaboration. Continued investment in digital health technologies, coupled with targeted interventions in high-burden states and vulnerable populations, will be essential to accelerate progress toward the long-term goals of the WHO End TB Strategy and India's vision of a TB-free nation.

Chapter – 8 Recommendation

Based on the findings of this study, encompassing an analysis of India's tuberculosis burden, gaps across the TB care cascade, government initiatives, and digital health interventions ,the following recommendations are proposed to accelerate progress toward TB elimination in India:

8.1 Strengthen Active Case Finding and Early Diagnosis

- Expand community-based TB screening programmes in high-burden states such as Uttar Pradesh, Chhattisgarh, Rajasthan, and Madhya Pradesh, prioritising underserved rural and peri-urban populations.
- Scale up deployment of rapid molecular diagnostic tools — including Xpert MTB/RIF and Truenat — to primary health centres and sub-district facilities to reduce diagnostic delays.
- Integrate AI-powered chest X-ray interpretation platforms (e.g., qXR, DeepCXR, NIDAAN) into routine mass screening to compensate for radiologist shortages in peripheral settings.
- Implement systematic symptom screening at all points of care, including outpatient departments, antenatal clinics, and community health worker interactions, to ensure no symptomatic individual is missed.

8.2 Close Gaps in the TB Care Cascade

- Address attrition between TB diagnosis and treatment initiation by establishing rapid linkage mechanisms, including same-day treatment initiation where feasible, and dedicated case managers for vulnerable patients.
- Strengthen referral coordination between public and private healthcare providers through enhanced use of the Nikshay platform and mandatory notification enforcement to reduce the 'missing cases' burden.
- Expand access to universal Drug Susceptibility Testing (DST) at the time of TB diagnosis, moving beyond the current 58% coverage toward the 98% national target.
- Introduce patient navigation support — including community health workers, counsellors, and peer educators — to guide patients through each step of the care cascade and reduce loss to follow-up.

8.3 Expand Tuberculosis Preventive Treatment (TPT)

- Prioritise scaling up TPT among all household contacts of bacteriologically confirmed pulmonary TB patients, targeting a coverage rate well above the current national average of 24%.
- Ensure systematic LTBI screening among all people living with HIV (PLHIV) registered at ART centres, with prompt initiation of preventive treatment for eligible individuals.
- Train healthcare workers at peripheral facilities on LTBI identification, TPT eligibility criteria, and adherence counselling, with structured monitoring and supervisory support.
- Decentralise TPT services to community health centres and primary care settings to improve geographic access, particularly in high-burden districts.

8.4 Integrate Management of Comorbidities

- Mandate bidirectional screening for diabetes mellitus in all notified TB patients, with seamless referral pathways to diabetes management services; current gaps show only 62.3% of co-infected patients being initiated on anti-diabetic treatment.
- Strengthen TB-HIV collaborative services, ensuring routine HIV testing for all TB patients and early ART initiation for co-infected individuals.
- Improve referral of TB patients who use tobacco and alcohol to cessation and de-addiction services; currently, only 31.6% of tobacco users and 33.5% of alcohol users among notified TB patients are being referred.
- Develop integrated care pathways that address TB alongside non-communicable diseases, mental health, and nutritional support within primary and secondary health facilities.

8.5 Accelerate Digital Health Integration

- Expand the Nikshay digital platform to encompass real-time, end-to-end tracking of patients across the entire TB care cascade — from presumptive case identification to post-treatment follow-up and relapse monitoring.
- Institutionalise the use of AI-based adverse outcome prediction models nationwide to proactively identify patients at high risk of treatment failure or loss to follow-up, enabling early targeted intervention.
- Leverage the National Federated Learning Platform (NHA and IIT Kanpur) to validate and continuously improve AI diagnostic tools while preserving patient data privacy under ICMR ethical guidelines.
- Invest in digital health literacy among frontline health workers and district programme managers to optimise adoption and utilisation of digital TB tools.
- Harness telemedicine and mobile health platforms to extend specialist TB consultation and treatment support to remote and underserved geographies.

8.6 Strengthen Public-Private Partnership

- Enhance engagement with the private healthcare sector through systematic outreach, capacity building, and financial incentives for TB notification, diagnosis, and treatment under the NTEP framework.
- Improve documentation and reporting standards in the private sector, moving toward integrated electronic health records that interface with Nikshay to reduce underreporting.
- Develop standardised treatment protocols and quality benchmarks for private providers managing TB, with regular performance monitoring and feedback mechanisms.

8.7 Address Social Determinants and Reduce Stigma

- Design and implement sustained public awareness campaigns at district and sub-district levels to improve TB symptom recognition, reduce stigma, and encourage early health-seeking behaviour.
- Expand Direct Benefit Transfer (DBT) coverage under the Nikshay Poshan Yojana beyond the current 70% to reach all notified TB patients, mitigating the financial barriers that drive catastrophic healthcare expenditure.
- Integrate social protection measures — including nutritional support, income assistance, and employment safeguards — into the TB care package, particularly for marginalised populations.
- Involve community leaders, civil society organisations, and TB survivor networks in programme planning, implementation, and advocacy to build trust and reduce social exclusion of patients.

8.8 Target High-Burden States with Differentiated Strategies

- Deploy additional resources, technical support, and intensified supervision to the highest-burden states — Uttar Pradesh, Maharashtra, Madhya Pradesh, Rajasthan, and Chhattisgarh — which together account for a disproportionate share of India's TB DALYs and mortality.
- Develop state-specific action plans informed by local epidemiological data, health system capacity, and socioeconomic context, rather than relying solely on uniform national strategies.

- Draw lessons from lower-burden states such as Kerala and Jammu & Kashmir to identify transferable best practices in TB prevention, diagnosis, and programme management.

8.9 Establish Robust Post-Treatment Follow-Up

- Institute structured post-treatment follow-up programmes for all TB patients at 6 and 12 months to detect relapse, recurrence, and long-term morbidity early.
- Strengthen drug-resistance surveillance systems to track emerging resistance patterns and ensure timely initiation of appropriate second-line therapy.
- Create TB survivor registries and longitudinal cohort studies to build evidence on long-term outcomes, informing future programme improvements.

8.10 Invest in Research, Surveillance, and Workforce Capacity

- Increase investment in operational research to generate Indian-specific evidence on the effectiveness of new diagnostic tools, treatment regimens, and digital health interventions across diverse settings.
- Strengthen the national TB surveillance system to reduce the gap between estimated and notified cases, with particular emphasis on tribal, migrant, urban slum, and prison populations.
- Expand and sustain training programmes for healthcare workers including ASHA workers, auxiliary nurse midwives, and district TB officers to build a competent, motivated TB workforce at all levels of the health system.

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