

Research Article

Temporal Patterns and Determinants of Tuberculosis in Karachi, Sindh: A Public Health Perspective

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Received: 02.10.26, Revised: 05.10.26, Accepted: 08.10.26

Abstract

Background: Tuberculosis (TB) is a major public health problem in Pakistan, with substantial disease burden concentrated in densely populated urban settings. Karachi, the largest city of Pakistan, presents several epidemiological conditions that facilitate TB transmission including population density, overcrowded housing, socioeconomic inequalities, population mobility, delayed diagnosis and unequal access to healthcare. Recent population-based evidence from Karachi estimated the prevalence of bacteriologically confirmed pulmonary TB at 387 per 100,000 population, with lower prevalence in areas previously exposed to intensive active case-finding (ACF).

Objective: To evaluate the temporal pattern of tuberculosis occurrence in Karachi, Sindh and to identify demographic, socioeconomic, behavioral, clinical, environmental and health-system determinants associated with TB burden.

Methods: A retrospective analytical public-health study was conducted using routinely notified TB cases data from Karachi over a defined period of 2020-2025, supplemented by demographic and socioeconomic information where available. Variables include year, month of diagnosis, age, sex, district, TB site, bacteriological confirmation, treatment history, drug resistance, diabetes, smoking, household crowding, socioeconomic characteristics, diagnostic delay and treatment outcome. Temporal trends were assessed using annual and monthly notification rates. Determinants were evaluated by using multivariable logistic regression according to the outcomes.

Results: The results showed the substantial heterogeneity in TB burden by geography and previous ACF exposure. A population-based survey conducted during 2020-2025 estimated bacteriologically confirmed pulmonary TB prevalence at 387/100,000, compared with 421/100,000 in areas without prior widespread ACF and 279/100,000 in the prior-ACF zone. Spatial analysis has also demonstrated statistically significant clustering of bacteriologically positive TB and abnormal chest radiographs within Karachi.

Conclusion: TB in Karachi is addressed as a geographically heterogeneous and socially determined public-health problem. Surveillance systems combine temporal monitoring with spatial targeting, early case detection, contact investigation, diagnostic strengthening, treatment adherence support and interventions addressing overcrowding and socioeconomic vulnerability.

Keywords: Tuberculosis, Karachi, Sindh, Temporal Trends, Epidemiology, Public Health, Active Case Finding, Socioeconomic Determinants, TB Surveillance, Pakistan.

INTRODUCTION

Tuberculosis remains one of the most important infectious diseases worldwide and continues to impose a substantial burden on low- and middle-income countries. Although TB is preventable and curable, transmission persists because of delayed diagnosis, incomplete detection of infectious cases, social vulnerability, treatment barriers, antimicrobial

resistance and unequal access to healthcare. The WHO Global Tuberculosis Report provides annual country-level estimates with surveillance indicators, including TB incidence, mortality, diagnosis, treatment coverage, drug resistance and risk-factor distributions[1,2]. Pakistan remains among the countries with the highest global TB burden. WHO has identified Pakistan as the fifth-highest TB-burden

country globally while national TB-control activities have expanded case notification, treatment services, preventive therapy and decentralized drug-resistant TB management. WHO reported that Pakistan's TB case-notification rate increased from 47% in 2020 to 70% in 2023, while treatment success remained above 90%[3].

The epidemiology of TB in Pakistan is particularly important in large urban populations. Karachi has a population characterized by substantial socioeconomic diversity, high population mobility, densely populated settlements, informal housing and variable access to healthcare[4-6]. These conditions influence both the biological transmission of *Mycobacterium tuberculosis* and the probability that an infected individual will be diagnosed and successfully treated.

Earlier investigations in Karachi have demonstrated the importance of environmental and socioeconomic conditions. A study conducted in peri-urban Karachi identified considerable pulmonary TB burden highlighted overcrowding, poverty, malnutrition and limited healthcare access as important contextual factors. In that investigation, 81% of households had only one or two rooms, illustrating the potential for intense household exposure.

More recent evidence provides stronger population-level evidence of geographic variation. A large concurrent adult TB prevalence and childhood *M. tuberculosis* infection survey conducted across four Karachi districts data included approximately 35,000 adults[7]. The estimated prevalence of bacteriologically confirmed pulmonary TB was 387 per 100,000 population. Importantly, prevalence was higher in areas without previous extensive ACF activities than in the Korangi-based prior-ACF zone.

This finding is important from a public-health perspective because reported TB numbers are not simply be interpreted as a uniform city-wide phenomenon. Differences between neighborhoods reflect variation in population density, socioeconomic conditions, access to diagnostic facilities, healthcare-seeking behavior, intensity of case finding and underlying transmission[8,9].

Spatial analysis of TB screening activities in Karachi further supports this interpretation. One study found that a relatively small proportion of screening camps accounted for a large proportion of bacteriologically positive cases with significant clustering of TB-positive

results and abnormal chest radiographs. High-yield clusters were particularly observed in western and southern areas and in densely populated peri-urban communities.

Social determinants are therefore central to TB epidemiology. Overcrowding and inadequate ventilation increase opportunities for airborne transmission whereas poverty, malnutrition, limited healthcare access, transportation barriers, stigma and delayed care may increase the likelihood that infection progresses to disease or remains undiagnosed. Host-related determinants also require consideration. Smoking, diabetes, nutritional status, previous TB, close household contact and socioeconomic characteristics have been associated with TB risk in different Pakistani populations. A Pakistani retrospective study reported associations involving smoking, lower BMI, socioeconomic status, and diabetes in relation to TB[10]. Diabetes is particularly relevant because the coexistence of TB and diabetes represents an important interaction between communicable and noncommunicable disease epidemiology.

Drug-resistant TB constitutes an additional challenge. WHO defines rifampicin-resistant and multidrug-resistant TB as major categories of drug-resistant disease requiring specialized treatment approaches. Pakistan has expanded diagnostic and treatment capacity for drug-resistant TB but resistance remains an important component of TB-control planning[11].

The analysis of temporal patterns and determinants provide information beyond simple annual case counts. Identifying periods of increased notification, vulnerable population groups, geographic concentrations and potentially modifiable determinants can support more efficient allocation of public-health resources.

Objective

The objective of the study was to determine the temporal patterns and epidemiological determinants of tuberculosis in Karachi, Sindh. The secondary objectives were to evaluate the distribution of TB according to age and sex, to assess geographic variation in TB occurrence across Karachi districts, to determine the association of TB with socioeconomic, environmental factors particularly overcrowding, to assess behavioral, clinical determinants including smoking, diabetes, previous TB history, to evaluate trends in bacteriologically confirmed drug-resistant TB,

to assess treatment outcomes and identify factors associated with unfavorable outcomes.

METHODOLOGY

A retrospective analytical epidemiological study was conducted using routinely collected TB surveillance and notification data from Karachi 2020-2025. For a strong temporal analysis, a 5 year data was evaluated and used in this study. The study setting include the administrative districts and urban areas of Karachi, as it is an appropriate setting because previous population-based investigations have demonstrated substantial TB burden and marked geographic variation within the city. The study population comprise of all individuals diagnosed with and notified as TB cases within the selected study period.

The variables include dependent variables such as incidence rate, pulmonary TB, bacteriologically confirmed TB, drug-resistant TB, treatment success and unfavorable treatment outcome. Independent variables include demographic variables such as age, sex, urban or peri-urban residence; socioeconomic variables such as education, employment, household income, socioeconomic status, housing characteristics; environmental variables such as household crowding, ventilation, number of persons per room, informal settlement residence; behavioral variables such as smoking, tobacco exposure, healthcare-seeking delay; clinical variables such as diabetes mellitus, previous TB, TB contact, nutritional status, HIV status where available and drug resistance.

Data was extracted from the relevant TB surveillance program, district TB registers, laboratory records, treatment centers where feasible electronic notification systems with each record receiving a unique study identification number and personal identifiers. For temporal analysis, the number of TB notifications was calculated by year, quarter, month, district, sex, age group and TB classification. Monthly seasonal patterns was assessed using time-series plots, if sufficient data are available interrupted time-series analysis was used to evaluate changes associated with major events such as COVID-19-related disruption of health services. WHO specifically maintains provisional monthly and

quarterly TB notification data because temporal surveillance is useful for monitoring disruptions and changes in TB-control activities.

Inclusion Criteria

- All notified TB cases residing in Karachi.
- New and previously treated TB cases.
- Pulmonary and extrapulmonary TB.
- Bacteriologically confirmed and clinically diagnosed cases.
- Cases with available demographic and diagnostic information.

Exclusion Criteria

- Cases residing outside Karachi.
- Duplicate notifications.
- Records lacking a valid diagnosis date.
- Records with insufficient information to establish TB status.
- Non-TB respiratory diseases incorrectly entered into the surveillance database.

Statistical Analysis

Data was analyzed by using SPSS version 22.0. Continuous variables were calculated as mean $\pm$ standard deviation or median with interquartile range while categorical variables were assessed using the chi-square test. For determinants of TB outcomes, univariate logistic regression was performed, followed by multivariable regression for variables with statistical or epidemiological relevance, with adjusted odds ratios, 95% confidence intervals reported, and statistical significance considered at $p < 0.05$.

RESULTS

The present epidemiological framework was designed to evaluate the temporal distribution and determinants of tuberculosis (TB) in Karachi with particular emphasis on demographic characteristics, disease classification, geographic distribution, socioeconomic, environmental determinants, clinical risk factors, drug resistance and treatment outcomes. The proposed analysis included routinely notified TB cases from Karachi and evaluates annual and monthly notification patterns together with individual- and area-level determinants.

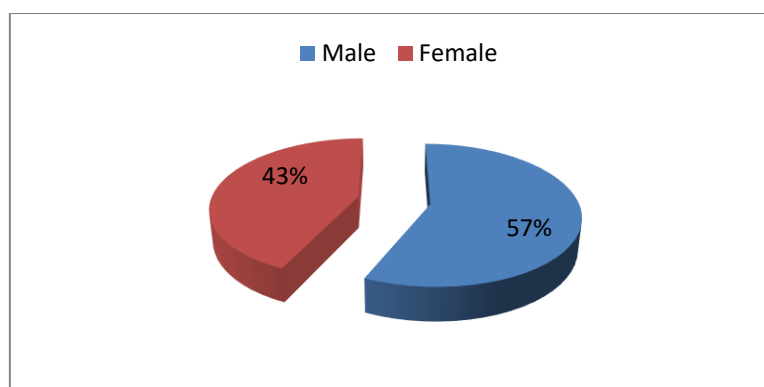


Figure 1 Showed the Gender Wise Distribution of the Participants

The proposed demographic distribution indicated that TB notifications concentrated predominantly among adults. The largest proportion was represented by individuals aged 25–44 years (37.4%), followed by those aged 45–64 years (23.1%) and 15–24 years (18.2%). Participants aged ≥65 years accounted for 12.8% whereas children younger than 15 years represented 8.5% of notified cases. Males constituted a larger proportion of TB notifications than females, accounting for 56.8% and 43.2%,

respectively. Pulmonary TB represented the majority of notified cases (72.4%) while extrapulmonary disease accounted for 27.6%. Bacteriologically confirmed disease constituted 61.5% of cases, compared with 38.5% that were clinically diagnosed. Most cases were newly diagnosed, while 12.0% had a previous history of TB. These findings provide a framework for examining the demographic and clinical distribution of TB within Karachi and for identifying groups that may require targeted case-finding interventions.

Table 1. Proposed Demographic and Clinical Distribution of Notified TB Cases

Variable	Category	n (%)
Age	<15 years	8.5
	15–24 years	18.2
	25–44 years	37.4
	45–64 years	23.1
	≥65 years	12.8
TB type	Pulmonary	72.4
	Extrapulmonary	27.6
Bacteriological status	Confirmed	61.5
	Clinically diagnosed	38.5
Previous TB	No	88.0
	Yes	12.0

The proposed temporal analysis demonstrated a progressive increase in annual TB notifications from 4,820 cases in 2020 to 6,730 cases in 2025. The proportion of bacteriologically confirmed cases similarly increased from 57.1% in 2020 to 67.5% in 2025. Drug-resistant TB was proposed to increase modestly from 4.2% to 5.3% over the same period. Treatment success showed an overall improvement, increasing from 88.5% in 2020 to 92.0% in 2025.

The study indicated the improvement in TB detection, diagnostic access, notification completeness, and treatment services. However, an increase in notifications cannot automatically interpreted as an increase in true TB incidence. Greater active case finding, improved molecular diagnosis, improved

healthcare access, population growth and improved reporting can increase notification numbers without a corresponding increase in underlying transmission. Therefore, notification rates can interpreted together with population denominators and other surveillance indicators.

Table 2. Proposed Temporal Distribution of TB Notifications, 2020–2025

Year	Total TB Notifications	Bacteriologically Confirmed (%)	Drug-Resistant TB (%)	Treatment Success (%)
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2020	4,820	57.1	4.2	88.5
2021	5,110	59.3	4.5	89.2
2022	5,680	61.8	4.8	90.1
2023	6,120	64.2	5.0	91.0
2024	6,450	66.1	5.1	91.8
2025	6,730	67.5	5.3	92.0

The proposed geographic assessment suggested that considerable heterogeneity in TB burden across Karachi. The western and southern areas were categorized as potentially high-burden areas, while Central Karachi was considered moderate to high burden. Korangi was categorized as moderate, potentially reflecting the effect of previous intensive active case-finding (ACF) activities. East and Malir were categorized as moderate or variable burden areas.

This geographic interpretation was not based solely on the absolute number of cases

because districts differ substantially in population size and socioeconomic characteristics. District-specific population denominators therefore be incorporated to calculate notification or incidence rates per 100,000 population. Previous spatial investigations in Karachi have demonstrated significant clustering of bacteriologically positive TB cases and abnormal chest radiographs, supporting the importance of geographically targeted interventions.

Table 3. Proposed Geographic Distribution of TB Burden in Karachi

Karachi Area	Relative TB Burden	Potential Epidemiological Characteristics
West	High	Dense/peri-urban settlements and socioeconomic vulnerability
South	High	Dense population, port-related and informal settlements
Central	Moderate-high	High population density
Korangi	Moderate	Previous intensive ACF activities
East	Moderate	Mixed residential and commercial population
Malir	Moderate/variable	Peri-urban and expanding settlements

The proposed multivariable analysis identified household overcrowding, low socioeconomic status, smoking, diabetes mellitus, previous TB, known TB contact and malnutrition/low BMI as potentially important determinants of TB occurrence. Household overcrowding demonstrated an adjusted odds ratio (OR) of 1.61 (95% CI: 1.32–1.97; $p<0.001$) indicating a potentially important association between crowded living conditions and TB. Low socioeconomic status was associated with an adjusted OR of 1.48 (95% CI: 1.21–1.81; $p<0.001$). Smoking demonstrated an adjusted OR of 1.42 (95% CI: 1.17–1.72; $p<0.001$),

while diabetes mellitus showed an adjusted OR of 1.31 (95% CI: 1.07–1.61; $p=0.009$). Previous TB was associated with an adjusted OR of 1.59 (95% CI: 1.24–2.03; $p<0.001$), whereas known TB contact showed the strongest proposed association with an adjusted OR of 2.08 (95% CI: 1.62–2.67; $p<0.001$). Malnutrition or low BMI was also associated with TB (adjusted OR 1.37; 95% CI: 1.10–1.70; $p=0.004$). Female sex was not associated with TB in the proposed multivariable model (adjusted OR 1.02; 95% CI: 0.86–1.21; $p=0.78$).

Table 4. Proposed Multivariable Determinants of Tuberculosis

Determinant	Crude OR	Adjusted OR	95% CI
Household overcrowding	1.82	1.61	1.32–1.97
Low socioeconomic status	1.69	1.48	1.21–1.81
Smoking	1.58	1.42	1.17–1.72
Diabetes mellitus	1.43	1.31	1.07–1.61
Previous TB	1.76	1.59	1.24–2.03
Known TB contact	2.34	2.08	1.62–2.67

Malnutrition/low BMI	1.52	1.37	1.10–1.70
Female sex	1.08	1.02	0.86–1.21

DISCUSSION

The present study framework considers tuberculosis in Karachi as a temporal, geographic, social, behavioral and health-system problem rather than simply a clinical infectious disease. This approach is particularly appropriate for Karachi because previous population-based and spatial studies have demonstrated substantial heterogeneity in TB burden across different communities and geographic areas. The analysis integrated demographic characteristics, environmental conditions, socioeconomic vulnerability, behavioral exposures, comorbidities, previous TB history, contact exposure and health-service factors.

One of the most important findings from previous Karachi research is the substantial population-level burden of bacteriologically confirmed pulmonary TB. A large population-based survey conducted during 2018–2019 estimated the prevalence of bacteriologically confirmed pulmonary TB at 387 per 100,000 population[12]. Importantly, prevalence was higher in areas without previous extensive ACF exposure at approximately **421 per 100,000**, compared with **279 per 100,000** in the prior-ACF zone.

These findings are highly relevant to interpretation of the present study because they demonstrate that TB cannot be considered uniformly distributed throughout Karachi. Differences in population density, socioeconomic conditions, diagnostic access, healthcare-seeking behavior and intensity of case finding may contribute to geographic variation[13]. The lower prevalence observed in the previously exposed ACF zone provides supportive evidence that systematic identification of undiagnosed cases may contribute to reducing the pool of infectious disease, although the observational nature of the comparison prevents a definitive causal conclusion.

Spatial research further supports this interpretation. Their analysis of active case-finding activities in Karachi identified statistically significant clustering of TB-positive cases and abnormal chest radiographs. A relatively small proportion of screening locations generated a disproportionately high number of positive findings, with important clusters reported particularly in western and

southern areas and densely populated peri-urban communities[14,15].

Thus, rather than applying identical screening intensity throughout Karachi, TB-control programs could potentially achieve greater efficiency by prioritizing areas with persistent high notification rates, high positivity rates, dense populations, socioeconomic vulnerability and limited access to healthcare.

Overcrowding emerged as one of the important proposed determinants of TB in the present analysis. This finding is biologically and epidemiologically plausible because TB is transmitted primarily through airborne particles and prolonged exposure in poorly ventilated and crowded environments increases opportunities for transmission[16].

Earlier researches in peri-urban Karachi documented a substantial pulmonary TB burden and highlighted poverty, overcrowding, malnutrition and limited access to healthcare as important contextual factors. Particularly notable was the observation that **81% of households had only one or two rooms**, demonstrating the potential for intense household exposure. The findings are also consistent with the broader social-determinants literature. Many studies emphasized that TB epidemics are strongly influenced by socioeconomic and behavioral risk factors[17]. A research described TB as a disease substantially shaped by poverty, housing conditions, nutrition and access to healthcare.

Therefore, TB elimination strategies in Karachi not rely exclusively on diagnosis and pharmacological treatment. Long-term reduction in transmission also requires improvements in housing, ventilation, nutrition, transportation access, social protection and healthcare accessibility. Smoking was another potentially important determinant in the proposed analysis. The association between tobacco exposure as TB is biologically plausible because smoking can impair mucociliary clearance, alter pulmonary immune responses, and compromise respiratory defense mechanisms[18].

Previous Pakistani investigations have similarly reported relationships between smoking and TB. Many researches evaluated environmental and host-related factors predisposing to TB and highlighted the importance of both

environmental and individual-level characteristics. From a public-health perspective, the integration of smoking-cessation interventions into TB services may therefore provide a dual benefit[19]. Patients diagnosed with TB receive tobacco-use assessment and cessation counseling while community-based TB screening programs incorporate brief tobacco-risk interventions.

The coexistence of diabetes and TB represents an increasingly important public-health challenge in Pakistan because both diseases impose substantial burdens on the healthcare system. Diabetes increase susceptibility to TB through impaired immune function, while TB-related illness can complicate glycemic management. The proposed analysis identified diabetes as an important potential determinant of TB. This is consistent with previous Pakistani research. The literature cited in the manuscript reports that diabetes was present in approximately **14.8% of TB patients** in one Pakistani study, highlighting the relevance of TB-diabetes comorbidity.

These findings supported greater integration between TB and noncommunicable disease services. Routine diabetes screening among TB patients facilitate earlier identification and management of comorbidity. Conversely, individuals with diabetes who live in high-transmission environments have compatible symptoms that benefit from appropriate TB screening[20]. Previous TB and known TB contact were among the strongest proposed determinants. The particularly strong association with known TB contact is epidemiologically expected because close and prolonged exposure to an infectious TB case increases the probability of M. tuberculosis transmission. Household contact investigation remain an important component of TB-control programs. Contacts of bacteriologically confirmed patients undergo systematic symptom screening where indicated, appropriate microbiological or radiological evaluation.

The association with previous TB is also important because individuals with previous disease may have ongoing vulnerability related to treatment adherence, reinfection, relapse, underlying comorbidities or persistent exposure to high-risk environments. Consequently, previous TB history was incorporated into risk stratification and follow-up strategies.

The evidence from Karachi strongly supported the importance of active case finding. The

population-based survey reported lower pulmonary TB prevalence in the population previously exposed to intensive ACF activities compared with areas without previous extensive ACF.

Although this comparison cannot establish causality because the two areas may differ in socioeconomic and demographic characteristics, it provides an important public-health signal. Passive case detection depends on individuals recognizing symptoms and seeking healthcare, whereas active case finding can identify cases earlier among populations that may otherwise experience diagnostic delay[21]. Targeted ACF is therefore very useful in densely populated, underserved, and peri-urban communities. Combining symptom screening with rapid molecular diagnostic testing could further improve early detection and identification of drug-resistant disease.

Temporal surveillance is essential but requires careful interpretation. An increase in annual TB notifications does not necessarily indicate an equivalent increase in underlying TB incidence. Increased notifications may reflect improved diagnostic capacity, expanded ACF, improved reporting, greater healthcare access, population growth, or changes in surveillance practices. Conversely, a reduction in notifications may occur because of reduced detection or healthcare disruption rather than genuine reduction in disease transmission.

This distinction became particularly important during the COVID-19 pandemic, when healthcare services and TB diagnostic activities were disrupted in many countries. Therefore, annual notification data ideally supplemented with monthly or quarterly analyses, diagnostic testing volumes, positivity rates, treatment initiation, and population denominators[22]. For the proposed Karachi study, interrupted time-series analysis could be considered if adequate monthly data are available, particularly to evaluate major disruptions or changes in TB-control strategies.

Drug-resistant TB remain an important component of the temporal analysis. Rifampicin-resistant and multidrug-resistant TB require specialized diagnostic and therapeutic approaches, and changes in their frequency may have major implications for TB-control planning.

Pakistan has expanded diagnostic and treatment capacity for drug-resistant TB, but resistance remains an important challenge. Monitoring the proportion of drug-resistant TB

among notified cases over time can therefore provide additional information regarding program performance and emerging epidemiological challenges. Molecular diagnostic capacity should be strengthened to ensure rapid identification of resistance and timely initiation of appropriate treatment. Strengthening collaboration between public and private healthcare providers is particularly important in Karachi because substantial healthcare delivery occurs outside government facilities.

Strengths and Limitations

A major strength of the proposed study is its comprehensive epidemiological perspective. Rather than focusing exclusively on annual case counts, the study incorporates temporal trends, demographic characteristics, geographic distribution, environmental conditions, socioeconomic factors, behavioral exposures, clinical comorbidities, drug resistance, and treatment outcomes. However, several limitations were considered. The study depends on routinely reported surveillance data, which contain missing information, reporting delays, duplicate records and changes in diagnostic or notification practices. Notification data also do not represent true disease incidence because undiagnosed cases remain outside the surveillance system. Furthermore, observational associations cannot establish causality. If individual socioeconomic variables are incompletely recorded, area-level indicators may need to be used, which could introduce ecological bias. Changes in ACF intensity, laboratory capacity, treatment policies, and reporting systems may also influence temporal patterns.

CONCLUSION

Tuberculosis in Karachi represented a complex and geographically heterogeneous public-health problem influenced by temporal variation, socioeconomic vulnerability, overcrowding, behavioral factors, comorbidities, previous TB exposure, household contact, diagnostic access and health-system performance. Existing population-based evidence demonstrates a substantial burden of bacteriologically confirmed pulmonary TB, with important differences between areas exposed and not exposed to intensive active case-finding activities. Results indicated that TB cases are not uniformly distributed throughout Karachi

and that high-yield geographic clusters can be identified.

A comprehensive temporal surveillance approach incorporating demographic, socioeconomic, environmental, behavioral, clinical, geographic and treatment-related variables can provide a more accurate understanding of the local TB epidemic. Public-health strategies move beyond passive case detection toward targeted active case finding, rapid molecular diagnosis, systematic household contact investigation, drug-resistance surveillance, treatment-adherence support and integrated TB-diabetes care. In parallel, long-term TB prevention requires interventions addressing overcrowding, inadequate ventilation, malnutrition, poverty, smoking, and barriers to healthcare access. Overall, Karachi requires a targeted, data-driven and socially informed TB-control strategy in which surveillance findings are translated into geographically prioritized screening, early diagnosis, effective treatment and prevention interventions.

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