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Where Do Patients Receive Tuberculosis Treatment in Indonesia? A Nationwide Spatial Analysis of Cross-Province Care, 2022–2025

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Abstract

Background

Tuberculosis services may extend beyond administrative boundaries, yet national evidence on cross-province treatment in Indonesia remains limited. This study examined the geographical distribution of recorded cross-province care, characteristics associated with receiving treatment outside the province of residence, and spatial relationships between residential origins and

treatment destinations. The aim was to identify priority provincial connections for service planning and coordination.

Methods

We conducted a nationwide retrospective observational analysis of records from Indonesia's Tuberculosis Information System for 2022–2025. Residential and facility provinces were harmonised into 34 geographical units. Descriptive statistics, provincial inflow and outflow profiles, and bilateral concentration measures characterised treatment patterns. Modified Poisson regression estimated adjusted prevalence ratios (aPRs). Poisson pseudo-maximum likelihood models examined distance and adjacency across 4,488 origin–destination–year cells, incorporating origin-year and destination-year fixed effects. Sensitivity analyses assessed alternative record selections and spatial specifications. Counts represented treatment records rather than verified unique patients or documented referral journeys.

Results

Among 2,977,475 geographically eligible treatment records, 103,635 (3.48%) involved cross-province care. Recorded annual proportions ranged from 2.76% in 2022 to 4.00% in 2023. The five largest bilateral province pairs accounted for 50.02% of these records, led by DKI Jakarta–West Java (22.49%). Hospitals accounted for 71.7% of cross-province records and showed higher adjusted prevalence than community health centres (aPR, 3.20; 95% confidence interval [CI], 2.24–4.57). Doubling interprovincial distance was associated with smaller expected flows (count ratio, 0.36; 95% CI, 0.32–0.40). The hospital and distance associations remained consistent across sensitivity analyses, whereas adjacency estimates varied with geographical specification.

Conclusion

Cross-province tuberculosis care accounted for a small share of the national total but was concentrated within specific provincial relationships. These findings support prioritising coordination among provinces sharing substantial treatment activity and reporting service use by both residence and facility location. Linked longitudinal records are needed to determine whether these care arrangements influence treatment continuity and outcomes.

Keywords: Tuberculosis; Cross-province care; Spatial analysis; Health services utilisation; Indonesia

Background

Tuberculosis (TB) remains a major challenge for health systems despite the availability of effective diagnosis and treatment. The World Health Organization (WHO) estimated that 10.7 million people developed TB and 1.23 million died from the disease in 2024, with Indonesia accounting for approximately one tenth of global incident cases [1]. Addressing this burden requires more than expanding the number of people diagnosed and treated. Services must also be organised around where people live, where they obtain care, and how support is maintained throughout treatment. WHO recommendations emphasise person-centered treatment and care, placing service delivery and patient support alongside effective therapeutic regimens [2]. Understanding the geography of treatment is therefore relevant to both service planning and programme coordination.

Indonesia provides an important setting for examining these issues. Its geographically dispersed population receives care through a decentralised health system involving community health centres, hospitals, and other public and private providers [3]. The national TB inventory study also demonstrates the importance of considering providers beyond routinely notified services when interpreting programme data [4]. Within this setting, administrative boundaries do not necessarily coincide with the areas served by healthcare facilities. The distinction between where patients reside and where they obtain treatment is consequently important. Access encompasses the ability to recognise healthcare needs, seek services, reach providers, and obtain appropriate care [5]. For TB programmes, these dimensions create a practical need to connect facility-based treatment with support available in patients' residential communities [6].

Relevant research can be considered in three complementary strands: patient pathways and service utilisation, treatment outcomes and cross-regional care, and spatial assessments of disease and service accessibility. Together, these strands provide a foundation for examining the relationship between residential location and treatment location, while also revealing questions that remain insufficiently addressed.

The first strand examines how patients navigate healthcare services. Patient-pathway analyses across five countries demonstrated mismatches between the providers initially consulted and the availability of TB diagnostic and treatment services [7]. In Indonesia, a national and subnational analysis similarly highlighted differences between care-seeking patterns and service availability, supporting approaches adapted to provincial circumstances [8]. Research in Bandung subsequently documented complex pathways involving multiple providers before diagnosis and treatment [9]. Comparisons before and during the COVID-19 pandemic identified further changes in delays and

provider encounters [10]. Economic studies reinforce the importance of these pathways: Indonesian patients continued to incur costs when seeking TB care after the introduction of universal health coverage [11], and a recent Bandung study found that multiple provider encounters were associated with higher pretreatment expenditure [12]. These studies explain important features of service navigation, but do not directly quantify nationwide relationships between provinces of residence and treatment.

The second strand concerns treatment outcomes and care across regional boundaries. Fitriangga and colleagues analysed more than one million Indonesian TB records from 2020–2022 and documented variation in treatment outcomes across patient groups and regions [13]. A subsequent systematic review and meta-analysis, co-authored by Fitriangga, examined loss to follow-up among people receiving treatment for drug-sensitive TB in the WHO South-East Asia Region [14]. These findings establish the relevance of treatment retention and regional differences, but outcome-based analyses alone do not capture the connections between patients' residential provinces and the provinces that provide treatment. Identifying those connections addresses a different service-delivery question.

Evidence from China demonstrates that cross-regional TB care warrants specific investigation. A hospital-based study described transregional treatment seeking among people with multidrug-resistant TB in northern China [15]. Research in Beijing examined local and non-local patients and the geographic distribution of care seeking [16]. More recently, a national study analysed interprovincial transfers during 2018–2022, including patient flows and arrival at receiving services [17]. A study in Guizhou examined mobility and travel distance for drug-resistant TB treatment and their associations with loss to follow-up [18]. These investigations support the

examination of care beyond administrative boundaries. However, their definitions distinguish treatment seeking, registered transfers, and mobility. A difference between the recorded residence and the treatment location does not automatically establish migration, referral, or transfer during treatment.

The third strand applies spatial methods to TB epidemiology and service accessibility. A systematic review documented varied approaches to mapping, clustering, and modelling TB, while emphasising that findings depend on data sources, geographic resolution, and analytical choices [19]. Recent research in West Java examined geographic access to drug-resistant TB diagnostic and treatment services and its relationship to case notification and loss to follow-up [20]. Such analyses help identify geographic differences in disease burden or proximity to services. Nevertheless, proximity to a facility and the location where treatment is actually recorded are different measures. An origin–destination approach adds information by explicitly linking residential areas to the areas that supply care.

These strands leave a specific evidence gap for national TB service planning in Indonesia. Patient-pathway studies describe encounters across providers, outcome studies identify groups with less favourable treatment results, and accessibility studies assess geographic service coverage. Less is established about the nationwide distribution and concentration of recorded treatment across provincial boundaries. In particular, an overall cross-province percentage cannot identify whether care is dispersed across many provincial relationships or concentrated within a small number of high-volume pairs. Nor can it distinguish provinces that serve substantial numbers of non-residents from those whose residents frequently obtain treatment elsewhere. These distinctions matter when interpreting the geography of service use.

Cross-province care should not, however, be treated as evidence of programme failure. A facility outside the residential province may be geographically convenient or provide appropriate services. The programmatic question is whether the observed pattern is recognised in planning and coordination. Identifying major origin–destination relationships can help prioritise communication between programmes, clarify responsibilities for treatment support, and distinguish the workload of destination facilities from the treatment needs of resident populations. These are potential applications of geographic evidence, rather than proof that cross-province care results in additional costs, treatment interruptions, or adverse outcomes.

This study therefore examines where TB treatment is recorded relative to patients' provinces of residence in Indonesia using national surveillance data from 2022–2025. It aims to quantify annual cross-province care, describe provincial inflows and outflows, identify the concentration of treatment within directional routes and bilateral province pairs, and examine associated demographic, clinical, and facility characteristics. A secondary spatial flow analysis assesses geographic associations after accounting for differences in origin year and destination year. Geographic units are harmonised across the study period, and sensitivity analyses assess dependence on record duplication, geographic restrictions, study years, and modelling choices. The findings are intended to inform service planning and interprovincial coordination; they describe recorded service relationships rather than verified patient journeys or causal effects.

Methods

Study design and setting

We conducted a nationwide retrospective observational study using routinely collected tuberculosis (TB) surveillance records from Indonesia for 2022–2025. The primary analysis

examined the association between recorded patient and facility characteristics and receipt of treatment outside the province of residence. A secondary ecological analysis examined the distribution of cross-province treatment records across origin–destination pairs and years. The primary analysis was therefore record-based, whereas the spatial flow analysis used province-pair–year cells. Reporting was guided by the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement and its extension for studies using routinely collected health data, the RECORD statement [21, 22].

The study period covered four annual surveillance extracts spanning 2022–2025. Year was defined using the cohort-year field supplied in the source data rather than reconstructed from treatment dates. The analysis characterised recorded service utilisation during this period; it did not follow individuals' movements between facilities or estimate the causal effects of receiving care across provincial boundaries.

Conceptual framework

The study adopted a service-utilisation perspective informed by the patient-centred access framework described by Levesque and colleagues [5] and WHO guidance on TB treatment and care [6]. These perspectives recognise that obtaining appropriate care involves interactions between population characteristics, service availability, and the organisation of healthcare delivery. However, the present dataset did not measure all dimensions of access. The framework was therefore used to organise interpretation rather than to construct a composite access index or test a complete causal model.

The analysis distinguished two complementary dimensions. The first concerned geographic concordance: whether the province of the facility associated with a treatment record matched the recorded province of residence. The second concerned interprovincial service relationships: how cross-province treatment records were distributed between residential origins and facility destinations. Together, these dimensions allowed the analysis to identify characteristics associated with cross-province care and describe where such care was concentrated.

Cross-province care was not treated as an intrinsically adverse outcome. A facility outside a residential province may be convenient, appropriate, or preferred. Conversely, geographic concordance does not establish that care was accessible or continuous. Associations were interpreted as descriptions of recorded service utilisation rather than evidence of referral, migration, inadequate local services, or treatment-related harm.

Data source and study population

Data were obtained from the supplied national extract of Indonesia's Tuberculosis Information System, *Sistem Informasi Tuberkulosis* (SITB). The database contained demographic characteristics, residential geography, facility information, clinical classifications, treatment history, dates, and recorded outcomes. SITB has previously been used to investigate national TB treatment outcomes in Indonesia [13].

The combined source database contained 2,988,098 records: 638,646 for 2022, 729,935 for 2023, 792,343 for 2024, and 827,174 for 2025. Records were eligible for the geographic analyses if they belonged to the study years and had interpretable provinces of residence and associated healthcare

facility. Records without either geographic field were excluded from analyses requiring paired locations. Eligibility was assessed before applying exclusions for missing covariates.

The analytical unit was a recorded TB treatment entry. A verified unique patient or treatment-episode identifier was unavailable; consequently, multiple records could not be reliably linked to the same person. The term "patient characteristics" refers to characteristics recorded in these entries, and counts should not be interpreted as verified numbers of unique individuals.

Definition of cross-province care

Cross-province care was defined as a difference between these two provinces after geographic harmonisation:

$$Y_r = \begin{cases} 1, & O_r \neq D_r, \\ 0, & O_r = D_r, \end{cases}$$

where O_r denotes the harmonised residential province and D_r the harmonised facility province for record r.

This definition described the relationship between two recorded locations. It did not establish the sequence of care, the presence of a formal referral, or the occurrence of a transfer during treatment. No international movement was examined.

Geographic harmonisation and spatial data

Province names were standardised by correcting recognised naming variants, removing excess whitespace, and applying a consistent coding scheme. To maintain comparable geographic units

across the study period, the analysis used 34 harmonised provincial units. South Papua, Central Papua, and Highland Papua were combined with the parent province of Papua; Southwest Papua was combined with West Papua. The same harmonisation rules were applied to both provinces of residence and treatment facility locations.

This harmonisation reduced differences arising from the use of changing administrative labels. However, it also excluded genuine crossings between newly established provinces within the same parent unit. The primary estimand was therefore cross-province care between the 34 harmonised units, not between all contemporary provincial boundaries. Results based on the original recorded labels were retained as a descriptive comparison.

Administrative polygons were obtained from the GADM version 4.1 Indonesia level-1 boundary dataset [23]. Spatial processing was performed using the sf package [24]. Polygons were checked for validity, matched to the study province names, and combined where necessary to reproduce the harmonised units.

For distance calculations, a representative land point was generated for each provincial polygon. Geodesic distances between these points were calculated in kilometres. These distances represented geographic separation between provincial units, not actual patient journeys, road-network distances, or distances between residential addresses and facilities. Provincial adjacency was initially defined by polygon contact at either a shared boundary segment or a point.

Selection and coding of explanatory variables

Explanatory variables were selected according to their relevance to recorded service utilisation and their availability across the four study years. Variables were not selected using univariable statistical significance.

Age was grouped as <15, 15–24, 25–44, 45–64, and ≥65 years. Values below zero or above 120 years were considered invalid. Sex was harmonised into female and male categories; unrecognised or missing values were treated as missing.

Facility type was derived from the recorded jenis field and classified as community health centre, hospital, clinic, independent practitioner, correctional facility, lung health centre, or treatment centre. Treatment history was classified as new treatment, relapse, treatment after previous loss to follow-up, treatment after failure, other retreatment, or unknown. Diagnostic classification distinguished bacteriologically confirmed and clinically diagnosed TB, while anatomical site distinguished pulmonary and extrapulmonary disease. Cohort year and province of residence were also included.

The reference categories were age 25–44 years, female sex, community health centre, new treatment, bacteriologically confirmed TB, pulmonary TB, and 2022. Province-of-residence fixed effects were included to account for measured differences in baseline cross-province care across residential origins.

HIV and diabetes variables were not included because consistent clinical harmonisation across all four annual extracts had not been established. Their exclusion should not be interpreted as evidence that these conditions are unrelated to service utilisation.

Data processing and missing information

Data cleaning included assessment of variable types, missingness, category consistency, geographic matching, and annual record counts. The primary descriptive analyses retained geographically eligible records with missing age or sex. The adjusted individual model excluded records with missing or invalid age or sex; no imputation was performed. The explicitly recorded unknown treatment-history category was retained.

Exact duplicate rows were identified using all original source variables before selecting analytical fields. These rows were retained in the primary analysis because, without a verified identifier, identical entries could not conclusively be classified as duplicate registrations rather than distinct but indistinguishable records. A separate sensitivity analysis removed exact duplicates.

All geographic and modelling exclusions were documented. Aggregate totals were checked to ensure that the number of outgoing cross-province records equalled the number of incoming records across the complete national dataset.

Descriptive and concentration analyses

Continuous characteristics were summarised using medians and interquartile ranges, and categorical characteristics using frequencies and percentages. Annual cross-province proportions used all geographically eligible records in the corresponding year as the denominator.

Provincial profiles distinguished residence-based and facility-based measures. The outgoing proportion was the number of residents recorded as receiving treatment outside their province, divided by the total number of eligible treatment records among residents of that province. The

incoming proportion was the number of records involving residents of other provinces, divided by the total number of eligible records associated with facilities in the destination province. Net inflow was calculated as incoming minus outgoing cross-province records. These measures were not interpreted as population-based TB incidence or migration rates.

Concentration was examined using directional routes and bilateral province pairs. A directional route represented residence in province i and treatment in province j; the reverse direction was counted separately. A bilateral pair combined both directions:

$$B_{ij} = N_{ij} + N_{ji}, \qquad i < j.$$

Routes and bilateral pairs were ranked by recorded volume. Their shares and cumulative shares used all cross-province treatment records as the denominator. Summaries included the contributions of the largest routes and pairs and the number required to account for selected cumulative shares. These measures described concentration among cross-province records, not the proportion of residents receiving care elsewhere.

Primary individual association model

Modified Poisson regression with a log link and robust variance estimation was used to estimate adjusted prevalence ratios (aPRs) for cross-province care [25, 26]. The model included age group, sex, facility type, treatment history, diagnostic classification, anatomical site, cohort year, and province-of-residence fixed effects.

The conditional mean was specified as:

$$\log\{E(Y_r \mid X_r)\} = \beta_0 + \boldsymbol{\beta}^{\mathsf{T}} X_r + \delta_{O_r},$$

where *Xr* represents the recorded explanatory characteristics and δ_{O_r} the residence-province fixed effect. Exponentiated coefficients were interpreted as prevalence ratios within the analysed records, not causal risk ratios.

For computational efficiency, records with identical model covariates and the same facility province were aggregated into frequency cells. For each cell \(c\), the number of cross-province records e_c was modelled with the logarithm of the total cell count \(n_c\) as an offset:

$$\log\{E(e_c \mid X_c)\} = \log(n_c) + \beta_0 + \boldsymbol{\beta}^{\mathsf{T}} X_c + \delta_{O_c}.$$

This aggregation preserved the Poisson estimating equations and the clustering structure. Cell counts were not treated as independent participants or survey weights.

Standard errors were clustered by the 34 harmonised facility provinces using an HC0 sandwich covariance estimator with a $G/(G-1)$ cluster correction [27]. Confidence intervals and two-sided tests used a t distribution with $G-1$ degrees of freedom. Model checks included convergence, coefficient estimability, covariate support, and fitted probabilities exceeding 1.

Secondary origin–destination flow model

The spatial extension examined annual counts of recorded cross-province treatment. All directional pairs between different harmonised provinces were included, producing $34 \times 33 \times 4 = 4{,}488$ province-pair–year cells. Pairs without observed cross-province records in the extract

were assigned zero. These zeros represented absence of recorded care in the dataset, not confirmed absence of actual service use.

Poisson pseudo-maximum likelihood (PPML) was used because it accommodates zero counts without requiring a logarithmic transformation of the outcome [28]. The conditional mean was specified as:

$$E(N_{ijt} \mid Z_{ij}, \alpha_{it}, \gamma_{jt}) = \exp\left[\alpha_{it} + \gamma_{jt} + \beta_1 \log(d_{ij}) + \beta_2 A_{ij}\right],$$

where N_{ijt} is the recorded count from residential province i to facility province j in year t, d_{ij} is geographic distance, and A_{ij} indicates adjacency. Origin-year and destination-year fixed effects, α_{it} and γ_{jt}, accounted for differences in recorded cross-province volumes at each endpoint over time. The model consequently examined allocation between origins and destinations rather than population-based disease rates.

The distance coefficient was reported as an expected count ratio per doubling of distance, $\exp\{\beta_1 \log(2)\}$.The adjacency coefficient was reported as $\exp(\beta_2)$. Primary standard errors were clustered in two dimensions, by origin and destination province [29], with t - based inference using the smaller cluster count minus one degree of freedom.

Diagnostics included convergence, coefficient identification, fitted-count validity, zero origin-year or destination-year margins, Pearson dispersion, and agreement between fitted and observed endpoint totals. Redundant nuisance fixed-effect columns were documented. Covariance eigenvalues were examined, and no automatic positive-semidefinite correction was applied. These

checks did not establish that all forms of dependence within the provincial network had been captured.

Visualisation and model interpretation

Maps displayed schematic links from residential to facility provinces, with arrow width proportional to recorded treatment volume. Nodes represented provincial geographic points rather than facility coordinates. Route-selection rules and the share of records represented were documented.

Observed and fitted flow maps used the same 40 highest-volume observed directional routes and the same width scale. Heatmaps described observed-to-fitted ratios, with cells having pooled fitted counts below five masked to limit unstable visual comparisons. Actual-versus-fitted plots were interpreted as in-sample assessments, not external validation or forecasts. An excess above fitted volume was not classified as evidence of inadequate services or inappropriate referral.

Sensitivity analyses

Sensitivity analyses assessed dependence on record selection, geographic definitions, study period, and covariance specification. The individual models were repeated after removing exact duplicates, excluding records with residence or facilities in either Papua parent unit, and restricting the study period to 2022–2024. Standard errors were also recalculated using residence-province clustering.

The flow models were repeated under the same three data restrictions. Additional specifications omitted adjacency, replaced representative-point distances with polygon-centroid distances, and

defined adjacency using a shared boundary line rather than point or line contact. An alternative covariance estimator clustered records by undirected provincial pair, grouping reciprocal directions and repeated years.

Comparisons considered effect sizes, confidence intervals, and substantive interpretation. No automatic threshold defined robustness, and differences between restricted populations were not treated as formal tests of coefficient equality. Sensitivity analyses were not selected based on whether they yielded statistically significant results. This study is reported in accordance with the STROBE statement and its RECORD extension for studies using routinely collected health data

Statistical software and ethical considerations

Analyses were implemented in R version 4.6.1 using data.table for processing, sandwich for robust covariance estimation, sf for spatial operations, ggplot2 for visualization, and gtsummary and gt for tables. Software versions were recorded through sessionInfo(). Estimates were presented with 95% confidence intervals; two-sided $P < 0.05$ was used as a conventional reference without replacing assessment of magnitude, precision, and sensitivity.

Data-access authorisation was granted on 1 September 2026, and the data were extracted on 18 September 2026. Ethical approval was granted by the Ethics Committee of the Faculty of Medicine, Universitas Tanjungpura, Indonesia, on 10 September 2026 (approval number: 8094/UN22.9/PT.01.04/2026). Individual informed consent was not required for this secondary analysis of routinely collected tuberculosis surveillance data.

Use of a large language model

ChatGPT (OpenAI) was used to assist drafting and English-language editing of the manuscript. The authors reviewed and verified the generated code, statistical outputs, interpretations, and references. All analytical decisions and final content remained under the authors' responsibility. ChatGPT was not used as a source of scientific evidence.

Result

Study population and characteristics

Of 2,988,098 source records, 2,977,475 had eligible information on both province of residence and facility province and were included in the geographic analysis. Among these, 2,873,840 records (96.52%) indicated treatment within the residential province, while 103,635 (3.48%) indicated cross-province care across the 34 harmonised geographic units.

The overall median age was 39 years (interquartile range [IQR], 21–55), and 57.6% of records were for males. Records involving cross-province care had a lower median age than those involving same-province care: 32 years (IQR, 22–49) versus 39 years (IQR, 21–55). Adults aged 25–44 years accounted for 36.5% of cross-province records, compared with 27.4% of same-province records. The corresponding proportions for those aged ≥65 years were 7.8% and 11.3%, respectively (Table 1)

Table 1. Characteristics of recorded tuberculosis episodes

Characteristic	Overall N = 2,977,475	Same province N = 2,873,840	Cross-province N = 103,635
Age, years	39.0 [21.0, 55.0]	39.0 [21.0, 55.0]	32.0 [22.0, 49.0]
Age group			
<15	498,948 (16.8%)	484,075 (16.8%)	14,873 (14.4%)
15-24	409,401 (13.8%)	391,342 (13.6%)	18,059 (17.4%)

25-44	825,097 (27.7%)	787,281 (27.4%)	37,816 (36.5%)
45-64	912,203 (30.6%)	887,426 (30.9%)	24,777 (23.9%)
>65	331,826 (11.1%)	323,716 (11.3%)	8,110 (7.8%)
Sex			
Female	1,262,716 (42.4%)	1,220,121 (42.5%)	42,595 (41.1%)
Male	1,714,759 (57.6%)	1,653,719 (57.5%)	61,040 (58.9%)
Source cohort year			
2022	633,968 (21.3%)	616,479 (21.5%)	17,489 (16.9%)
2023	724,753 (24.3%)	695,765 (24.2%)	28,988 (28.0%)
2024	791,724 (26.6%)	761,289 (26.5%)	30,435 (29.4%)
2025	827,030 (27.8%)	800,307 (27.8%)	26,723 (25.8%)
Treating facility type			
Community health centre	1,573,089 (52.8%)	1,546,822 (53.8%)	26,267 (25.3%)
Hospital	1,325,601 (44.5%)	1,251,343 (43.5%)	74,258 (71.7%)
Clinic	45,473 (1.5%)	43,583 (1.5%)	1,890 (1.8%)
Independent practitioner	5,263 (0.2%)	5,037 (0.2%)	226 (0.2%)
Correctional facility	15,035 (0.5%)	14,316 (0.5%)	719 (0.7%)
Lung health centre	12,942 (0.4%)	12,672 (0.4%)	270 (0.3%)
Treatment centre	72 (0.0%)	67 (0.0%)	5 (0.0%)
Region of residence			
Sumatra	571,474 (19.2%)	552,939 (19.2%)	18,535 (17.9%)
Java-Bali	1,851,211 (62.2%)	1,780,231 (61.9%)	70,980 (68.5%)
Kalimantan	154,556 (5.2%)	150,370 (5.2%)	4,186 (4.0%)
Sulawesi	211,625 (7.1%)	206,369 (7.2%)	5,256 (5.1%)
Nusa Tenggara	79,313 (2.7%)	77,626 (2.7%)	1,687 (1.6%)
Maluku	31,679 (1.1%)	30,488 (1.1%)	1,191 (1.1%)
Papua	77,617 (2.6%)	75,817 (2.6%)	1,800 (1.7%)
Previous TB treatment			
New	2,425,932 (81.5%)	2,345,391 (81.6%)	80,541 (77.7%)
Relapse	80,457 (2.7%)	78,037 (2.7%)	2,420 (2.3%)
After previous LTFU	30,282 (1.0%)	29,158 (1.0%)	1,124 (1.1%)
After treatment failure	15,457 (0.5%)	14,974 (0.5%)	483 (0.5%)

Other retreatment	1,218 (0.0%)	1,141 (0.0%)	77 (0.1%)
Unknown	424,129 (14.2%)	405,139 (14.1%)	18,990 (18.3%)
Recorded diagnostic classification			
Bacteriologically confirmed	1,434,080 (48.2%)	1,392,340 (48.4%)	41,740 (40.3%)
Clinically diagnosed	1,543,395 (51.8%)	1,481,500 (51.6%)	61,895 (59.7%)
Anatomical site			
Pulmonary	2,726,023 (91.6%)	2,635,332 (91.7%)	90,691 (87.5%)
Extrapulmonary	251,452 (8.4%)	238,508 (8.3%)	12,944 (12.5%)

Values are n (column %) or median [interquartile range]. Category percentages use non-missing observations; missing counts are shown separately. Unknown previous treatment history is retained as a substantive recorded category. Percentages may not total 100% due to rounding. LTFU, loss to follow-up. Cross-province care means that the recorded residence and treating facility are in different stable geographic units. Both locations were harmonised to 34 units: Papua Selatan, Papua Tengah and Papua Pegunungan were combined with Papua; Papua Barat Daya was combined with Papua Barat. This removes both administrative label differences and genuine crossings within those parent units. The unit of analysis is a recorded episode, not a verified unique person.

Hospitals accounted for 74,258 cross-province records (71.7%), whereas community health centres accounted for 26,267 (25.3%). Among same-province records, these proportions were 43.5% and 53.8%, respectively. Using all geographically eligible records within each facility category as the denominator, cross-province care represented 5.60% of hospital records and 1.67% of community health centre records.

Residents of Java–Bali accounted for 68.5% of cross-province records, compared with 61.9% of same-province records. Cross-province records also contained higher proportions of clinically diagnosed TB (59.7% versus 51.6%) and extrapulmonary TB (12.5% versus 8.3%). New treatment accounted for 77.7% of cross-province records and 81.6% of same-province records, while unknown treatment history accounted for 18.3% and 14.1%, respectively.

Annual patterns of cross-province care

The proportion of cross-province care increased from 2.76% in 2022 to 4.00% in 2023, before declining to 3.84% in 2024 and 3.23% in 2025. The corresponding numbers were 17,489, 28,988,

30,435, and 26,723 records. Thus, the highest annual proportion occurred in 2023, whereas the largest absolute number occurred in 2024.

Over the same period, the number of geographically eligible records increased from 633,968 in 2022 to 827,030 in 2025. Although the cross-province proportion declined after 2023, both its proportion and absolute count remained higher in 2025 than in 2022 (Supplementary Table S1).

Provincial inflows and outflows

Provincial profiles showed substantial differences between the volume of cross-province care and its contribution to provincial service use. DKI Jakarta received the largest number of records involving residents of other provinces (26,287), followed by Jawa Barat (21,598), Banten (13,807), Jawa Tengah (7,795), and Jawa Timur (3,961). DKI Jakarta, Jawa Barat, and Banten together accounted for 61,692 incoming cross-province records, representing 59.53% of the national cross-province total.

The highest proportion of non-resident treatment was recorded in DKI Jakarta, where 12.29% of eligible facility-based records involved residents of other provinces. This was followed by DI Yogyakarta (11.65%) and Banten (7.27%). In contrast, although Jawa Barat had the second-largest incoming volume, non-residents accounted for 2.78% of its facility-based records (Table 2).

Jawa Barat had the largest number of residents recorded as receiving treatment outside their province (22,668), followed by DKI Jakarta (19,583), Jawa Tengah (11,805), and Banten (9,276). However, the highest outgoing proportion was observed in DKI Jakarta (9.45%), followed by DI Yogyakarta (7.26%), Jambi (5.07%), Kalimantan Utara (5.07%), and Banten (5.00%). Nusa Tenggara Barat had the lowest outgoing proportion, at 0.91%.

DKI Jakarta had the largest positive net balance of cross-province records (+6,704), followed by Banten (+4,531) and DI Yogyakarta (+1,118). Jawa Tengah had the largest negative balance (−4,010), followed by Jawa Timur (−1,482) and Sumatera Utara (−1,411). Several provinces, including DKI Jakarta and DI Yogyakarta, therefore combined relatively high incoming and outgoing proportions rather than functioning exclusively as destinations or origins.

Table 2. Provincial inflows and outflows

Province	Residentepisodes	Outgoing	Treated_episodes	Incoming	Outgoing	Incoming	Net
DKI JAKARTA	2,07,178	19,583	213,882	26,287	9.45	12.2	6,704
JAWA BARAT	778,410	22,668	777,340	21,598	2.91	2.77	-1,070
BANTEN	185,434	9,276	189,965	13,807	5.00	7.26	4,531
JAWA TENGAH	326,334	11,805	322,324	7,795	3.61	2.41	-4,010
JAWA TIMUR	312,419	5,443	310,937	3,961	1.74	1.27	-1,482
SUMATERA UTARA	175,122	5,180	173,711	3,769	2.95	2.16	-1,411
DI YOGYAKARTA	22,531	1,636	23,649	2,754	7.26	11.6	1,118
SULAWESI SELATAN	95,045	1,898	95,717	2,570	1.99	2.68	672
RIAU	57,855	2,594	57,715	2,454	4.48	4.25	-140
SUMATERA BARAT	56,503	1,838	56,952	2,287	3.25	4.01	449
KALIMANTAN TIMUR	38,781	1,328	39,108	1,655	3.42	4.23	327
SUMATERA SELATAN	85,267	1,924	84,944	1,601	2.25	1.88	-323
LAMPUNG	72,980	2,210	72,262	1,492	3.02	2.06	-718
KALIMANTAN SELATAN	38,720	629	39,208	1,117	1.62	2.84	488
KALIMANTAN TENGAH	20,132	997	20,006	871	4.95	4.35	-126
KEPULAUAN RIAU	25,389	1,250	24,978	839	4.92	3.35	-411
BALI	18,905	569	19,124	788	3.00	4.12	219
JAMBI	27,448	1,392	26,802	746	5.07	2.78	-646
ACEH	46,282	1,215	45,683	616	2.62	1.34	-599
PAPUA	62,236	1,185	61,647	596	1.90	0.96	-589
SULAWESI TENGAH	29,590	929	29,257	596	3.13	2.03	-333
SULAWESI TENGGARA	23,684	800	23,467	583	3.37	2.48	-217

SULAWESI UTARA	32,897	781	32,690	574	2.37	1.75	-207
KALIMANTAN BARAT	49,248	843	48,978	573	1.71	1.16	-270
MALUKU	19,102	677	18,991	566	3.54	2.98	-111
NUSA TENGGARA BARAT	41,394	377	41,480	463	0.91	1.11	86
PAPUA BARAT	15,381	615	15,188	422	3.99	2.77	-193
NUSA TENGGARA TIMUR	37,919	1,310	37,014	405	3.45	1.09	-905
SULAWESI BARAT	14,126	611	13,888	373	4.32	2.68	-238
MALUKU UTARA	12,577	514	12,420	357	4.08	2.87	-157
GORONTALO	16,283	237	16,372	326	1.45	1.99	89
KEPULAUAN BANGKA BELITUNG	11,549	348	11,507	306	3.01	2.65	-42
BENGKULU	13,079	584	12,744	249	4.46	1.95	-335
KALIMANTAN UTARA	7,675	389	7,525	239	5.06	3.17	-150

Concentration within provincial pairs

Cross-province care was concentrated within a limited number of provincial relationships. When reciprocal directions were combined, DKI Jakarta–Jawa Barat was the largest bilateral pair, accounting for 23,304 records or 22.49% of all cross-province care. This comprised 12,693 records from Jawa Barat residents receiving treatment in DKI Jakarta and 10,611 in the reverse direction.

The next-largest bilateral pairs were Banten–DKI Jakarta (10,748 records; 10.37%), Banten–Jawa Barat (7,220; 6.97%), Jawa Barat–Jawa Tengah (6,145; 5.93%), and DKI Jakarta–Jawa Tengah (4,424; 4.27%). Together, these five pairs accounted for 51,841 records, representing 50.02% of all cross-province care. The ten largest bilateral pairs accounted for 60.07%, and the twenty largest accounted for 69.05%.

The directional analysis showed a similar concentration. The Jawa Barat to DKI Jakarta route was the largest, representing 12.25% of cross-province records, followed by DKI Jakarta to Jawa Barat (10.24%). The ten largest directional routes accounted for 50.08% of all cross-province records.

Percentages for bilateral pairs and directional routes describe alternative summaries of the same records and were not added together.

Characteristics associated with cross-province care

The adjusted individual model included 2,977,459 records after excluding 16 with missing or invalid age or sex. Relative to adults aged 25–44 years, cross-province care was less prevalent among children aged <15 years (adjusted prevalence ratio [aPR], 0.52; 95% confidence interval [CI], 0.38–0.72), adults aged 45–64 years (aPR, 0.59; 95% CI, 0.56–0.62), and those aged ≥65 years (aPR, 0.50; 95% CI, 0.47–0.53). The estimate for those aged 15–24 years was close to the reference category (aPR, 0.96; 95% CI, 0.86–1.06). Male sex was associated with a higher prevalence of cross-province care (aPR, 1.13; 95% CI, 1.07–1.19).

Facility type showed marked associations. Compared with community health centres, cross-province care was more prevalent in hospital records (aPR, 3.20; 95% CI, 2.24–4.57), clinics (aPR, 2.41; 95% CI, 1.82–3.20), independent practitioners (aPR, 2.92; 95% CI, 1.24–6.90), and correctional facilities (aPR, 2.09; 95% CI, 1.17–3.73). Estimates for lung health centres and treatment centres were imprecise, with confidence intervals including one (Table 3).

Table 3. Characteristic Associated with Cross-Province Care

Characteristic	Adjusted PR	95% CI	p-value
Age group			
25-44	Ref		
<15	0.52	0.38, 0.72	<0.001
15-24	0.96	0.86, 1.06	0.4
45-64	0.59	0.56, 0.62	<0.001
65	0.50	0.47, 0.53	<0.001

Sex				
Female	Ref			
Male	1.13	1.07, 1.19	<0.001	
Treating facility type				
Community health centre	Ref			
Hospital	3.20	2.24, 4.57	<0.001	
Clinic	2.41	1.82, 3.20	<0.001	
Independent practitioner	2.92	1.24, 6.90		16
Correctional facility	2.09	1.17, 3.73		14
Lung health centre	1.35	0.29, 6.32	0.7	
Treatment centre	3.10	0.43, 22.4	0.3	
Previous TB treatment				
New	Ref			
Relapse	0.89	0.83, 0.95	<0.001	
After previous LTFU	0.90	0.84, 0.96		3
After treatment failure	0.86	0.69, 1.08	0.2	
Other retreatment	1.49	0.67, 3.33	0.3	
Unknown	1.27	1.04, 1.56		22
Recorded diagnostic classification				
Bacteriologically confirmed	Ref			
Clinically diagnosed	1.07	0.92, 1.23	0.4	
Anatomical site				
Pulmonary	Ref			
Extrapulmonary	1.09	0.88, 1.36	0.4	
Source cohort year				
2022	Ref			
2023	1.40	1.28, 1.54	<0.001	
2024	1.37	1.24, 1.51	<0.001	
2025	1.18	1.08, 1.29	<0.001	

Compared with new treatment, relapse and treatment after previous loss to follow-up were associated with lower cross-province prevalence: aPRs were 0.89 (95% CI, 0.83–0.95) and 0.90 (95% CI, 0.84–0.96), respectively. Unknown treatment history was associated with higher prevalence (aPR, 1.27; 95% CI, 1.04–1.56). Confidence intervals included one for treatment after failure, other retreatment, clinically diagnosed TB, and extrapulmonary disease. While compared with 2022, adjusted prevalence remained higher in 2023 (aPR, 1.40; 95% CI, 1.28–1.54), 2024 (aPR, 1.37; 95% CI, 1.24–1.51), and 2025 (aPR, 1.18; 95% CI, 1.08–1.29).

Geographic associations with interprovincial flows

In the PPML analysis, greater geographic distance was associated with lower cross-province treatment counts after adjustment for origin-year and destination-year fixed effects. A doubling of distance corresponded to an expected count ratio of 0.36 (95% CI, 0.32–0.40; (P<0.001)). The adjacency estimate was 0.88 (95% CI, 0.54–1.44; (P=0.608)), providing no clear evidence of an additional association with sharing a provincial boundary under the primary specification (Supplementary Table S4).

Sensitivity analyses

Removing exact duplicate rows had little influence on the national cross-province proportion. The eligible population decreased from 2,977,475 to 2,975,682 records, and cross-province records decreased from 103,635 to 103,620; the proportion remained 3.48%. Excluding records with either endpoint in the Papua parent units yielded 3.49%, while restriction to 2022–2024 yielded 3.58% (Supplementary Table S2).

The hospital association remained similar across the restricted individual models, with aPRs of 3.20 after duplicate removal, 3.24 after excluding the Papua parent units, and 3.10 after restricting the period to 2022–2024. Residence-province clustering retained the primary point estimate of 3.20 but changed its confidence interval to 2.59–3.96.

Some treatment-history findings were less consistent. For treatment after previous loss to follow-up, the confidence interval included one with residence-province clustering ($P = 0.065$) and with restriction to 2022–2024 ($P = 0.052$). Conversely, treatment after failure showed a confidence interval excluding one in the 2022–2024 model (aPR, 0.85; 95% CI, 0.73–0.99), although its primary interval included one (Supplementary Table S3).

The PPML distance association was stable across specifications, with expected count ratios per doubling of distance ranging from approximately 0.357 to 0.359. Adjacency was more sensitive: replacing representative-point distances with centroid distances changed the estimate to 0.50 (95% CI, 0.31–0.81; ($P = 0.007$). Defining adjacency by a shared boundary line produced estimates identical to the primary specification, while pair-clustered inference retained an adjacency interval including one.

Rank correlations between primary and alternative fitted bilateral flows were high, ranging from 0.9903 for centroid distances to 1.0000 for the shared-boundary specification (Supplementary Table S5). These correlations indicated similarity in fitted rankings across specifications, but did not establish external predictive validity or stability of every geographic coefficient.

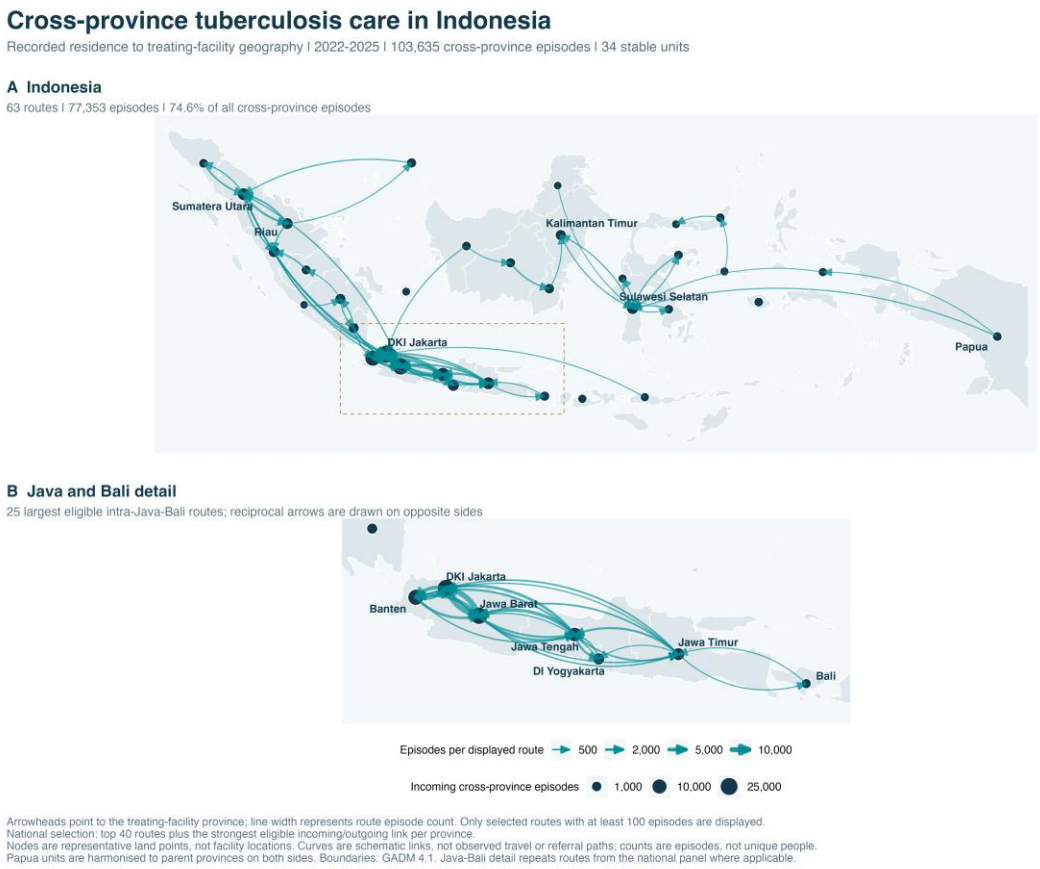


Figure 1. Cross Province Tuberculosis Care in Indonesia

Fig 1 shows the national map displays 63 selected cross-province treatment routes, comprising 77,353 records and representing 74.6% of all 103,635 cross-province records during 2022–2025. Arrowheads indicate the facility province, arrow thickness represents the number of records on each route, and node size reflects the total incoming cross-province volume. The largest displayed treatment relationships were concentrated in Java, particularly among DKI Jakarta, Jawa Barat, and Banten. The Java–Bali panel highlights reciprocal relationships between these provinces and connections involving Jawa Tengah, DI Yogyakarta, Jawa Timur, and Bali. Outside Java, selected links connect provinces within Sumatra, Kalimantan, and Sulawesi, as well as longer-distance connections between island groups.

These patterns show that recorded TB service use extends beyond provincial administrative boundaries and is concentrated within particular geographic relationships. They provide a basis for identifying priority provincial partnerships for service planning and treatment-support coordination. However, the map does not establish why care occurred outside the residential province or whether this affected treatment continuity.

Only selected routes are displayed; an absent arrow does not indicate an absence of cross-province care. The Java–Bali panel provides additional detail and should not be added to the national panel. Provincial points and curved links are schematic representations, not actual facility locations, patient journeys, or verified referral pathways.

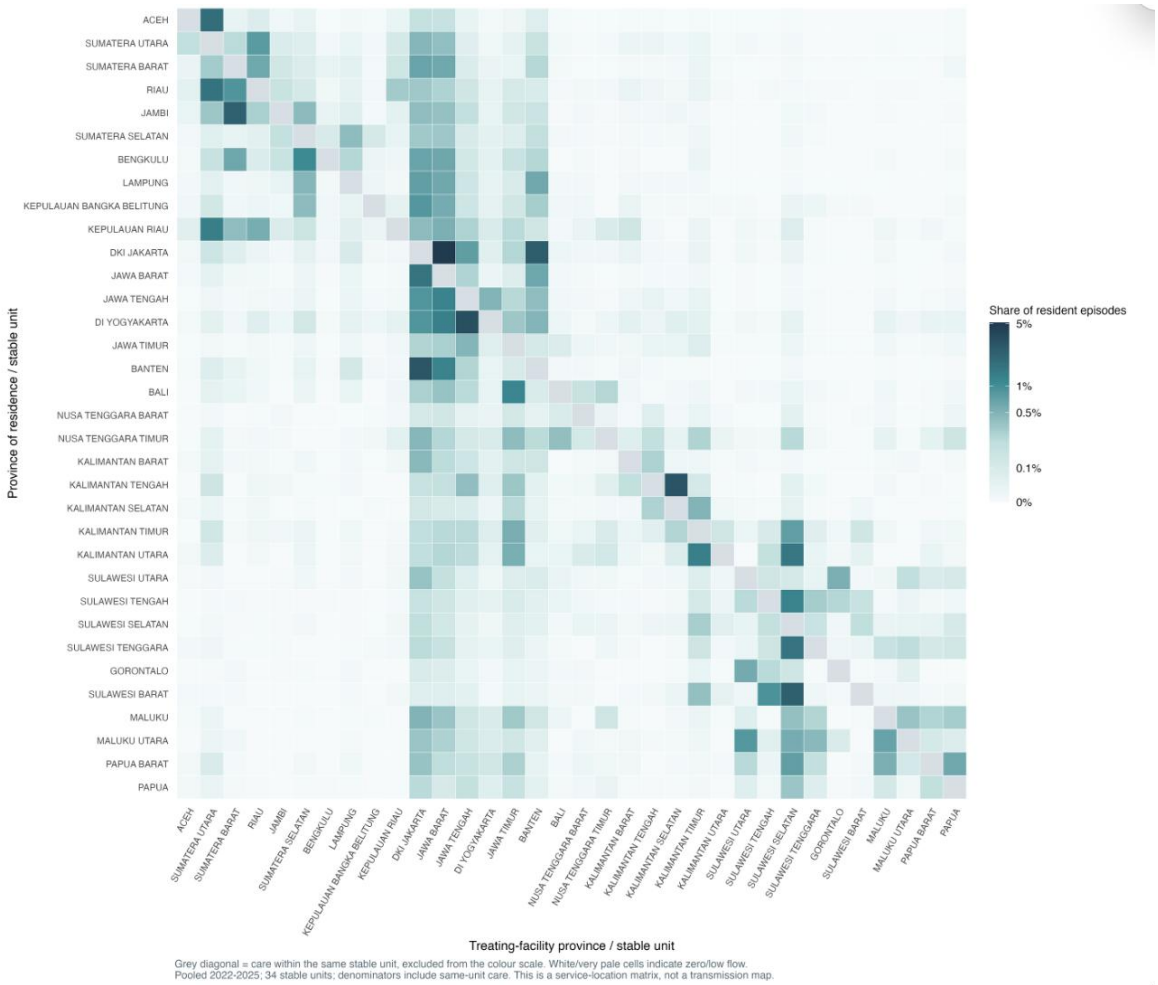


Figure 2. Where Residents receive recorded TB Treatment

The heatmap in Figure 2 shows the distribution of recorded tuberculosis treatment locations relative to patients' provinces of residence during 2022–2025. Each off-diagonal cell represents the percentage of all eligible treatment records originating in one province associated with facilities in another province. Darker colours indicate higher percentages. Grey diagonal cells represent treatment within the same harmonised provincial unit and are excluded from the colour scale.

Prominent cross-province relationships are visible among DKI Jakarta, West Java, and Banten, as well as between DI Yogyakarta and Central Java. Outside Java, notable connections include Aceh to North Sumatra, Jambi to West Sumatra, Central Kalimantan to South Kalimantan, and several Sulawesi provinces to South Sulawesi. The DKI Jakarta and West Java columns show connections with multiple residential origins, indicating geographically extensive service relationships.

The matrix also demonstrates directional differences. Reciprocal cells use different residential denominators; consequently, a darker cell indicates a greater share of an origin province's treatment records, rather than necessarily a larger absolute volume. These patterns complement the route-count analysis by identifying destinations that are relatively important for residents of particular provinces.

The findings can inform prioritisation of interprovincial coordination and information exchange. However, the heatmap describes recorded residence–facility relationships and does not establish formal referrals, actual travel distances, reasons for facility selection, or tuberculosis transmission pathways.

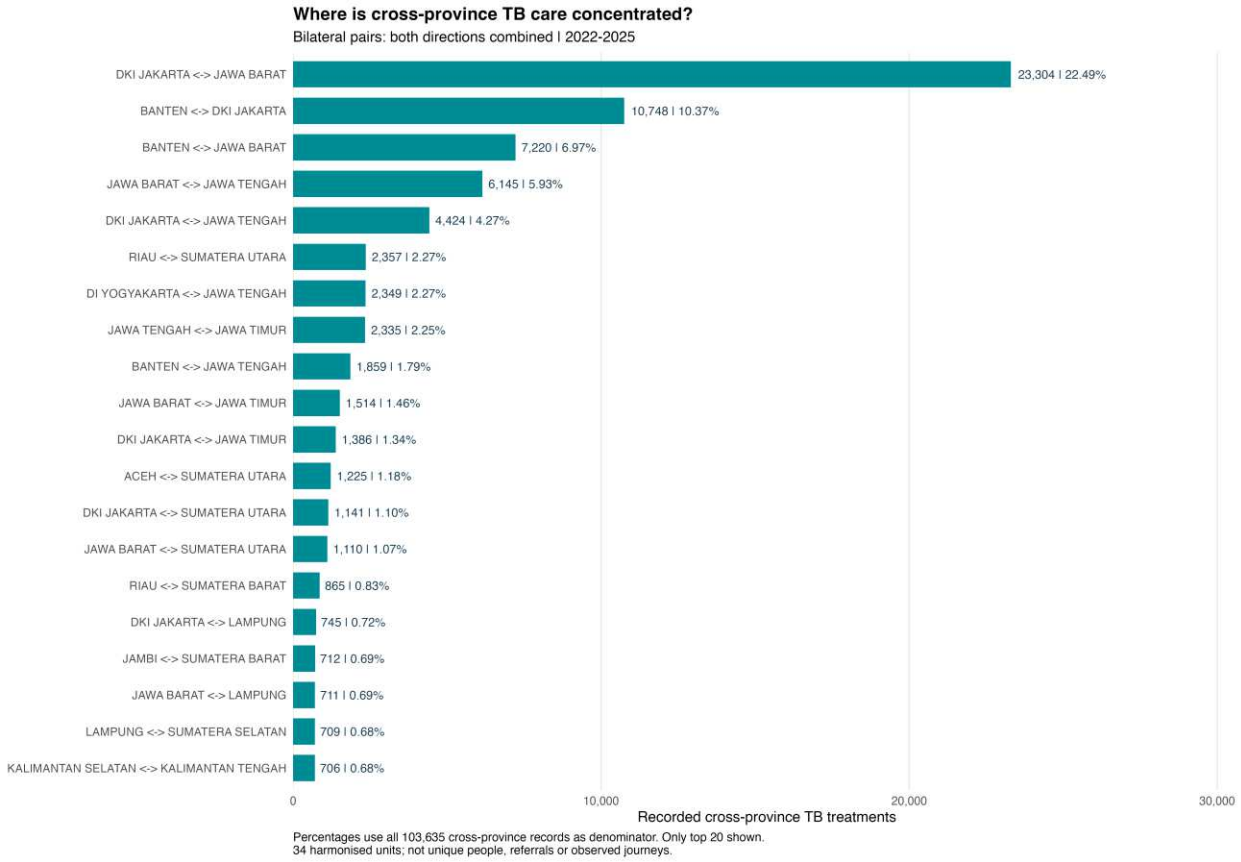


Figure 3. Cross-Province TB care concentrated

Cross-province tuberculosis treatment was concentrated within a small number of province pairs, predominantly in Java. DKI Jakarta–West Java accounted for the largest share, with 23,304 treatment records (22.49% of all 103,635 cross-province records), followed by Banten–DKI Jakarta (10,748; 10.37%) and Banten–West Java (7,220; 6.97%). Together, these three pairs represented 39.82% of all cross-province treatment records during 2022–2025. The five largest pairs, including West Java–Central Java and DKI Jakarta–Central Java, accounted for 50.02% of all cross-province records. The 20 pairs shown collectively represented 69.05%, indicating substantial geographical concentration. Outside Java, Riau–North Sumatra was the largest pair displayed, accounting for 2,357 records (2.27%). (Fig. 3)

These findings identify priority pairs of provinces to coordinate TB services, exchange treatment information, and support patient follow-up. Although cross-province care accounted for a relatively small proportion of all eligible treatment records nationally, its concentration in specific pairs suggests that targeted coordination could address a substantial share of this service activity.

Each pair combines records in both directions. Consequently, the figure does not establish the predominant direction of care, demonstrate balanced exchanges, or identify formal referrals. The findings describe recorded differences between patients' provinces of residence and those of their treatment facilities.

Discussion

This nationwide analysis identified a geographically concentrated pattern of cross-province tuberculosis care in Indonesia during 2022–2025. Among 2,977,475 treatment records with valid residence and facility province information, 103,635 (3.48%) involved care outside the province of residence after geographical harmonisation. Although most treatment was recorded within the same province, cross-province care was concentrated within a relatively small number of province pairs, particularly those connecting DKI Jakarta, West Java, and Banten. Hospital-based treatment was strongly associated with cross-province care in the individual-record analysis, while the spatial flow model identified a consistent inverse association between interprovincial distance and treatment flows. Together, these findings describe a service network that extends beyond provincial administrative boundaries and identify specific geographical relationships where coordination may be particularly relevant.

The principal contribution of this study is the integration of individual characteristics, provincial service balances, and origin–destination relationships within a national surveillance analysis. Earlier Indonesian patient-pathway research examined alignment between care-seeking behaviour and the availability of diagnostic and treatment services [8]. Our analysis adds a geographical perspective by identifying where recorded treatment occurs relative to patients' province of residence. This distinction matters because a province's resident TB population and the population treated by its facilities are not necessarily identical.

Geographical concentration and its programmatic significance

The national proportion of cross-province care should be interpreted alongside its absolute volume and geographical concentration. A proportion of 3.48% represents more than 100,000 treatment records over four years. More importantly, these records were distributed unevenly: DKI Jakarta–West Java alone accounted for 22.49% of all cross-province records, while the three largest bilateral pairs accounted for 39.82%. The five largest pairs represented approximately half of all cross-province care. Consequently, a relatively small national proportion can correspond to substantial coordination needs within particular provincial relationships.

The prominence of DKI Jakarta, West Java, and Banten is compatible with a pattern in which administrative boundaries intersect closely connected residential and healthcare catchment areas. However, the present data cannot distinguish whether these relationships arise from proximity to facilities, employment-related residence arrangements, patient preferences, specialist care, or formal referral. These explanations remain hypotheses. The observed concentration establishes the importance of these provincial connections without identifying the mechanisms responsible for them.

Provincial service balances provide additional information beyond bilateral totals. DKI Jakarta recorded more incoming than outgoing cross-province treatment, as did Banten and DI Yogyakarta. These positive balances indicate that their facilities treated more records involving residents of other provinces than their own residents generated elsewhere. Nevertheless, a positive balance does not establish that a province has higher-quality services, and a negative balance does not demonstrate inadequate local capacity. Such interpretations require information on facility capabilities, clinical complexity, referral indications, and patient preferences.

These findings suggest that planning based exclusively on residence may overlook part of the service workload borne by receiving provinces. Conversely, reporting treatment only by facility location may obscure the geographical distribution of patients' residential origins. Parallel reporting by residence and treatment location would therefore provide a clearer account of population needs and service activity. The study does not establish the financial consequences of these differences, but it identifies where a more detailed assessment of workload and resource requirements would be useful.

Facility type and individual characteristics associated with cross-province care

Hospitals accounted for approximately 71.7% of cross-province treatment records. After adjustment, hospital-based treatment was associated with a prevalence of cross-province care approximately 3.20 times that observed in community health centres. This association remained similar across the principal sensitivity analyses, suggesting that it was not explained by exact duplicate records, the inclusion of Papua-related geographical units, or the inclusion of 2025.

The hospital association is compatible with several service configurations. Hospitals may serve wider geographical catchment areas, provide services unavailable at some primary care facilities, or receive patients with more complex diagnostic and treatment needs. However, facility type and treatment location were observed together in the surveillance records. The analysis therefore cannot establish whether hospital care prompted cross-province attendance or whether patients attending facilities outside their province were more likely to select or be directed to hospitals.

Indonesian patient-pathway research has previously demonstrated that the facilities where patients initially seek care do not necessarily correspond to those where diagnoses or treatments are ultimately recorded [8]. This supports examining relationships across facility levels, but it also cautions against interpreting our hospital findings as evidence of a documented referral sequence. Our data describe the recorded facility location rather than the complete pathway through multiple providers.

Cross-province care was also associated with age and sex. Compared with records for people aged 25–44 years, adjusted prevalence was lower among children and older age groups, while male records had a modestly higher prevalence than female records. These differences may reflect variation in mobility, household support, employment, or care preferences. Nevertheless, socioeconomic circumstances, employment, access to transport, and reasons for facility selection were unavailable. The findings should therefore be interpreted as differences in recorded service use rather than evidence that particular groups experienced better or worse access.

Clinical characteristics provided less consistent evidence of independent associations. Although clinically diagnosed and extrapulmonary TB were more common among cross-province records descriptively, their adjusted confidence intervals included the null. The geographical pattern

therefore cannot be attributed to these measured clinical categories alone. Associations involving previous treatment history also warrant caution because some estimates were sensitive to the analytical period or clustering specification.

Distance and the organisation of interprovincial treatment flows

The spatial analysis identified a strong inverse association between geographical distance and cross-province treatment counts. Conditional on origin-year and destination-year fixed effects, doubling the distance between provincial representative points was associated with an expected flow approximately 0.36 times as large. This relationship remained similar across the spatial sensitivity analyses, providing consistent evidence that distance helps describe the distribution of recorded interprovincial care.

The distance estimate concerns aggregate flows rather than individual decisions. It does not mean that an individual patient's probability of crossing a provincial boundary decreases by a corresponding amount. Moreover, the model conditions on each province's annual outgoing and incoming cross-province totals. Its contribution is therefore to explain how these totals are distributed across pairs of provinces, rather than why a province generates or receives a particular overall volume of cross-province care.

The practical importance of geographical accessibility is supported by research in other TB settings. A study in Guizhou, China, examined patient mobility and travel distance in relation to loss to follow-up among people receiving treatment for drug-resistant TB [18]. Research in South Africa has likewise investigated travel distance and treatment retention in the context of rifampicin-resistant TB care [30]. These studies support further investigation of travel burden, but

their populations, geographical units, and treatment arrangements differ from those examined here. They cannot establish that the cross-province pattern observed in Indonesia caused treatment interruption.

Shared provincial borders did not show a consistent independent association across model specifications. The primary adjacency estimate included the null, whereas using alternative provincial representative points changed the estimate and its statistical interpretation. This sensitivity indicates that adjacency should not be presented as a stable determinant of treatment flows. Provincial polygons simplify complex geographical relationships, particularly in an archipelagic setting where transport connections may not closely align with shared land boundaries.

The actual and fitted maps showed that the model broadly reproduced major observed connections. However, these comparisons were conducted within the estimation sample. Agreement between fitted and observed maps therefore represents descriptive model fit rather than external predictive validation. Route-specific differences may identify connections for further investigation, but they do not independently establish unmet need, inappropriate referral, or exceptional service performance.

Implications for coordination and continuity of TB care

The most immediate programmatic implication is the opportunity to prioritise coordination between provinces with substantial shared treatment activity. Because approximately half of all cross-province records were concentrated within five bilateral pairs, reviewing these relationships could address a considerable share of recorded cross-province care. The appropriate response is to

examine whether existing arrangements adequately support patients who receive services across administrative boundaries.

For high-volume province pairs, practical priorities could include agreed communication channels between facilities and TB programme teams, verification of treatment responsibility when patients change providers, and reconciliation of treatment outcome information. These are proposed applications of the findings; their effectiveness was not evaluated in this study [31]. They are consistent with the emphasis on treatment support in WHO operational guidance and with Indonesia's recent programme review priorities concerning faster referrals, improved treatment success, and reduced loss to follow-up [6,32,33].

Monitoring should distinguish service activity from successful continuity of care. Counts of cross-province treatment identify where coordination may be needed, but they do not show whether communication occurred or whether treatment was completed. Future monitoring could assess whether the receiving provider was confirmed, whether subsequent treatment information was available, and whether outcomes were reconciled across facilities. Such indicators would require longitudinal linkage and additional information beyond the geographical fields used here.

Patient costs also deserve attention. Indonesian studies have documented expenditures incurred while seeking TB care, including transport and other non-medical costs [11,12]. Our analysis did not measure these expenditures, and crossing a provincial boundary does not necessarily imply a long or expensive journey. Nevertheless, the identified connections provide a basis for selecting settings in which to investigate actual travel burden and whether treatment support can be delivered closer to patients' homes when clinically appropriate.

These geographical findings complement previous national work by Fitriangga and colleagues on TB treatment outcomes and their determinants [13]. Whereas that study examined outcomes among recorded cases, the present analysis describes the relationship between residence and treatment location. Linking these dimensions in future research could help assess whether particular service configurations are associated with treatment completion or interruption. The current findings alone do not establish such an association.

Temporal variation and robustness of the findings

The annual proportion of cross-province care increased from 2.76% in 2022 to 4.00% in 2023, then declined to 3.84% in 2024 and 3.23% in 2025. The largest absolute number occurred in 2024, illustrating the discrepancy between the proportion of records involving cross-province care and the total volume of records. This temporal pattern should not be interpreted as evidence of programme improvement or deterioration without additional contextual information.

Changes may reflect differences in service use, reporting coverage, geographical coding, or the composition of recorded patients and facilities. WHO's 2025 review documented progress in Indonesia's TB surveillance, alongside ongoing gaps in reporting and digital integration [32]. Changes in surveillance coverage are therefore a plausible influence on observed trends, although their contribution could not be quantified in this analysis.

Sensitivity analyses supported the stability of the overall cross-province proportion, the hospital association, and the inverse distance relationship. Removing exact duplicates produced little change, while excluding Papua-related units or restricting the analysis to 2022–2024 retained the principal patterns. However, robustness was not uniform across all parameters. Some treatment-

history associations changed in statistical precision, and adjacency was sensitive to geographical specification. These differences strengthen the case for distinguishing the central findings from estimates that require more cautious interpretation.

Strengths and limitations

A major strength of this study is its national scale, covering almost three million geographically eligible treatment records over four years. Combining individual-record analysis with provincial balances and a complete interprovincial flow matrix provided complementary perspectives on the organisation of TB care. Inclusion of zero-flow province pairs in the spatial model and explicit sensitivity analyses further improved analytical transparency.

Several limitations nevertheless affect interpretation. First, the analysis included recorded treatment rather than all people with TB in Indonesia. Individuals who were undiagnosed, untreated, or unreported were outside the analytical population. Differences in reporting across providers or provinces could therefore influence the observed pattern. National coverage should not be equated with complete population ascertainment.

Second, the analytical unit was a treatment record. Without a verified unique patient identifier, the study could not determine whether multiple records represented separate treatment courses, transfers, or repeated entries for the same person. Removing exact duplicates addressed one form of repetition but could not resolve all possible duplication. Counts should therefore not be interpreted as unique patients or verified journeys.

Third, a difference between residence and facility province does not demonstrate physical relocation, formal referral, or repeated travel during treatment. Recorded residence may differ from

where a person was living when care was received. The data also did not reconstruct successive facilities, reasons for provider selection, or the timing of movement.

Fourth, harmonising geographical units to 34 stable provincial groupings improved comparability across years but reduced spatial detail. In particular, care across newly established provincial boundaries within the same harmonised parent unit was classified as within-province care. The reported proportion therefore applies to the harmonised geography and should not be presented as the proportion crossing all contemporary provincial boundaries.

Fifth, distance was measured between provincial representative points rather than patients' homes and treatment facilities. It did not capture road networks, ferry routes, air travel, journey time, or transport costs. The stability of the distance coefficient across alternative specifications supports its descriptive relevance but does not eliminate measurement limitations.

Sixth, the observational models could not control for several potentially important factors, including household resources, insurance arrangements, disease severity, facility capacity, and referral indications. Facility associations are consequently vulnerable to residual confounding and selection into treatment settings. Neither the individual-record nor spatial model identifies causal effects.

Finally, uncertainty estimation was constrained by the number of provincial clusters. The full two-way clustered covariance matrix in the primary spatial model was not positive semidefinite, although the covariance block for the focal geographical coefficients was positive definite. Together with the in-sample nature of model assessment, this warrants cautious interpretation of

inferential precision. The consistent distance relationship across sensitivity analyses is informative, but it does not constitute external validation.

Despite these limitations, the study identifies specific provincial relationships that would remain obscured by a national percentage alone. Its practical value lies in showing where cross-province treatment is concentrated and providing a basis for targeted investigation of service coordination, patient burden, and continuity of care.

Conclusion

This nationwide spatial analysis characterised cross-province tuberculosis care in Indonesia during 2022–2025 by integrating individual treatment records with provincial service balances and origin–destination flow modelling. Cross-province care accounted for 103,635 of 2,977,475 geographically eligible treatment records (3.48%). Despite this relatively small national proportion, treatment was highly concentrated within specific provincial relationships: the five largest bilateral pairs accounted for approximately half of all cross-province records. DKI Jakarta, West Java, and Banten formed the most prominent connections. Hospital-based treatment was consistently associated with a higher prevalence of cross-province care, while greater interprovincial distance was associated with smaller treatment flows. These findings describe geographical patterns of recorded care rather than causal effects, verified referral pathways, or treatment outcomes.

The concentration of cross-province care provides a practical basis for prioritising coordination between provinces with substantial shared service activity. Reporting by both residence and treatment location could help distinguish population needs from facility workloads, while targeted

review of high-volume connections could identify opportunities to strengthen information exchange and continuity of care. Programme responses should preserve access to appropriate services while addressing avoidable administrative and travel burdens. Future research linking treatment records across facilities, together with referral information, actual travel measures, and treatment outcomes, is needed to determine whether particular cross-province care arrangements support or compromise treatment completion

List of abbreviations

aPR	: Adjusted prevalence ratio
CI	: Confidence interval
GADM	: Global Administrative Areas
HC0	: Heteroskedasticity-consistent covariance estimator, type 0
IQR	: Interquartile range
LTFU	: Loss to follow-up
PPML	: Poisson pseudo-maximum likelihood
RECORD	: REporting of studies Conducted using Observational Routinely-collected health Data
SITB	: Sistem Informasi Tuberkulosis (Tuberculosis Information System)
STROBE	: Strengthening the Reporting of Observational Studies in Epidemiology
TB	: Tuberculosis
WHO	: World Health Organization

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Author contributions

IFEM and AF conceived the study and formulated the research questions. AF conducted data cleaning, statistical analysis, and spatial modelling. RA, MH, and NFY contributed to the analytical approach and interpretation of the findings. IWGAE and IAL provided methodological input and critically reviewed the statistical analyses. IFEM and AF drafted the manuscript. RA, MH, NFY, IWGAE, and IAL critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

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Data availability

The individual-level tuberculosis surveillance data analysed in this study are maintained by the Ministry of Health, Indonesia, and are not publicly available because of confidentiality and data governance restrictions. Access is subject to authorisation from the relevant Ministry of Health authority. Requests for access should be directed to the Indonesia National TB Program.

Declarations

Ethics approval and consent to participate

Ethical approval was granted by the Ethics Committee of the Faculty of Medicine, Universitas Tanjungpura, Indonesia, on 10 September 2026 (approval number: 8094/UN22.9/PT.01.04/2026). Permission to access and analyse the SITB data was granted by Indonesia National TB Program, Directorate of Communicable Diseases, Ministry of Health, Republic of Indonesia.

Consent for publication

Not applicable. This manuscript does not contain identifiable information about any individual.

Competing interests

The authors declare that they have no competing interests.

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- S4PPMLcomparison.xlsx
- RECORDChecklistSITB.pdf