ORIGINAL ARTICLE

Temporal, Spatial, and Seasonal Trends of Pneumonia, Pulmonary Tuberculosis, and Influenza in Thailand: Impacts of the COVID-19 Pandemic

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Abstract

Background: The COVID-19 pandemic and associated non-pharmaceutical interventions (NPIs) significantly disrupted respiratory disease transmission worldwide. However, comparative evidence across time, geography, and seasonality in Southeast Asia remains limited. To examine changes in incidence, spatial distribution, and seasonal patterns of pneumonia, pulmonary tuberculosis (TB), and influenza in Thailand across pre-pandemic, pandemic, and post-pandemic periods.

Methods: A retrospective longitudinal study was conducted using national surveillance data from all 77 Thai provinces (2014–2024). Monthly incidence rates were analyzed using negative binomial regression. Spatial patterns were visualized through choropleth maps and regional incidence rate ratios (IRRs). Seasonality was assessed using seasonal-trend decomposition (STL) and two-way ANOVA (Month×Period).

Results: Influenza incidence dropped sharply during 2020–2021 and rebounded over 30-fold post-pandemic (IRR_PD2=34.36, 95% CI: 24.26–48.72). Pneumonia declined by 37% in 2021 (IRR_D2=0.63, 95% CI: 0.41–0.96), and then rose significantly post-pandemic (IRR_PD2=1.97, 95% CI: 1.39–2.78). TB remained relatively stable. Influenza suppression was spatially uniform, with rebounds clustered in urban provinces. Pneumonia showed uneven regional resurgence; TB patterns remained geographically consistent. Seasonal cycles for all diseases re-emerged after the pandemic. Influenza exhibited a new mid-year peak, pneumonia aligned with rainy and winter months, and TB maintained a January–May peak.

Conclusions: The pandemic induced pathogen-specific shifts in respiratory disease dynamics in Thailand. Influenza and pneumonia showed marked suppression and atypical rebounds, while TB patterns remained steady. These findings underscore the need for adaptive surveillance, sustained TB services, and spatially responsive planning to strengthen future respiratory disease preparedness.

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Introduction

The COVID-19 pandemic profoundly altered the landscape of respiratory infections worldwide, with non-pharmaceutical interventions (NPIs), including mask use, distancing, and school closures, driving major reductions in incidence and transmission. In South Korea, influenza activity declined by 74.7% and remained suppressed through 2020, while pneumonia admissions decreased by 38% during periods of strict NPI enforcement, including a substantial decline observed in Thailand.[1-4] Global tuberculosis (TB) notifications also fell by 20–30%, with some centers reporting reductions up to 50%, reflecting widespread disruption of diagnosis and care.[5, 6] These large-scale “suppression experiments” have provided a rare opportunity to examine how broad public-health measures reshape both viral and bacterial respiratory diseases.

Influenza demonstrated one of the most striking effects of NPIs, showing >99% suppression of transmission across many countries during 2020–2021.[7] In tropical settings such as Senegal, the typical January–March influenza peak disappeared entirely, followed by off-season and unusually intense outbreaks once NPIs were relaxed, an outcome described as “immunity debt.”[8-11] Pneumonia and TB followed distinct but parallel patterns. Non-COVID community-acquired pneumonia admissions dropped by over half in the United States and across Europe, and detections of respiratory syncytial virus (RSV) among hospitalized patients fell from 25.6% to 5.0%.[12-14] TB services were particularly disrupted as case-finding programs were suspended, diagnostic laboratories diverted to COVID-19, and patient health-care–seeking behavior declined. Resulting notification backlogs persisted even after restrictions eased, with slower rebounds than observed for viral infections.[5, 6, 15, 16] These global findings together demonstrate that NPIs profoundly altered epidemiologic patterns across influenza, pneumonia, and TB, albeit with varying intensity and recovery trajectories.

In line with global observations, Thailand exhibited similar but variably documented shifts in respiratory disease dynamics during the COVID-19 period. A SARIMA-based analysis of national surveillance data showed pronounced suppression of influenza and pneumonia between 2020 and 2021, while tuberculosis (TB) notifications decreased by less than 2%, a change that was not statistically significant.[17] Factors shaping the resurgence of influenza included socioeconomic status, population density, seasonality, and public health measures, all of which have been examined in the Thai context.[18] Improvements in air quality associated with lockdowns were also linked to modest reductions in pneumonia admissions. In northeastern Thailand, mean daily pneumonia cases declined by approximately 12% during 2020–2021, and spatial clustering analyses revealed distinct regional transmission patterns.[19, 20] Furthermore, excess mortality analyses identified pneumonia as a major contributor to pandemic-related deaths in the country.[11] Collectively, these findings highlight pathogen-specific disruptions and regional variation in respiratory disease patterns, underscoring the need for integrated national analyses to compare temporal, spatial, and seasonal dynamics across multiple diseases.

Despite clear evidence that NPIs reshaped the transmission dynamics of influenza, pneumonia, and tuberculosis globally and within Thailand, comparative analyses that integrate their temporal, spatial, and seasonal dimensions remain limited. Previous Thai studies have tended to examine individual diseases or single time periods, leaving uncertainty about how each pathogen responded and recovered following pandemic-related disruptions. Addressing this gap requires a unified approach that evaluates these infections using consistent data and comparable analytic frameworks.

Accordingly, this study aims to analyze national surveillance data for pneumonia, pulmonary tuberculosis, and influenza across pre-pandemic, pandemic, and post-pandemic periods in Thailand. The specific objectives are to (a) investigate temporal variations in disease incidence, (b) examine spatial distribution and clustering across 77 provinces, and (c) assess changes in seasonal patterns, including peak incidence months and overall trends. These analyses provide an integrated understanding of pathogen-specific disruptions and recovery patterns in the respiratory disease landscape in Thailand.

Methods

Study Design and Setting

This retrospective longitudinal study analyzed national surveillance data from all 77 provinces of Thailand, including Bangkok, to assess the epidemiology of pneumonia, pulmonary tuberculosis (TB), and influenza across three distinct periods: pre-COVID (January 2014–December 2019), during COVID (January 2020–December 2021), and post-COVID (January 2022–December 2024). The post-COVID period was defined to begin in January 2022, reflecting the widespread relaxation of public health measures and a nationwide shift away from emergency pandemic response. This transition toward endemic management was later formalized by the Ministry of Public Health in October 2022, when COVID-19 was officially reclassified as an endemic disease in Thailand.

The climate in Thailand comprises three main seasons: summer (mid-February to mid-May), rainy (mid-May to mid-October), and winter (mid-October to mid-February), with the southern region experiencing only summer and rainy seasons due to distinct monsoonal patterns.

This study obtained ethical approval from the Human Research Ethics Committee at the University of Phayao (ID: HREC-UP-HSST 1.1/009/68).

Case Definitions and Data Sources

Monthly new-case counts were obtained from Thailand's national disease surveillance system via R506 reporting forms, which are part of the country's mandatory notifiable disease framework under the Ministry of Public Health. This system ensures systematic reporting of infectious diseases from all health facilities nationwide.[21]

Case definitions followed official R506 guidelines. Pneumonia was defined using ICD-10 codes J12–J18; pulmonary tuberculosis by A15–A19 and related extrapulmonary codes; and influenza by J10–J11. Case ascertainment included clinical diagnoses, radiological findings, laboratory confirmation, and epidemiological investigations, in line with national reporting criteria.[22] Provincial mid-year population estimates were retrieved from the Ministry of Interior and used to calculate monthly incidence rates (per 100,000 population).

Temporal Analysis

All temporal analyses were conducted using R (R Foundation for Statistical Computing, Vienna, Austria). Monthly incidence rates for each disease were plotted as time series to illustrate long-term trends, and as boxplots to examine variation by calendar month and by pandemic period. Seasonal-trend decomposition using Loess (STL) was applied to each disease series using periodic seasonal windows and default trend smoothing, isolating seasonal, trend, and irregular components.

Spatial Analysis

Annual incidence rates (per 100,000 population) were calculated for each province and mapped using R, with spatial visualization performed via the `sf`, `tmap`, and `ggplot2` packages. Choropleth maps were constructed using Thailand's provincial boundary shapefile (Royal Thai Survey Department, WGS 84), with fixed color intervals applied across all years to facilitate visual comparisons. Spatial variation in disease burden was interpreted using these maps alongside region-level IRRs across Thailand's seven health service regions.

Inferential Analyses

Three inferential strategies were employed to assess temporal variation in incidence across pandemic stages, regional disparities in spatial patterns, and shifts in seasonal dynamics of the three respiratory diseases. To assess temporal variation, negative binomial regression models were applied in SPSS (version 29) to estimate monthly incidence changes across pandemic stages. For each disease and province, 2019 served as the baseline, with indicator variables for 2020, 2021, and the post-COVID period (2022–2024). Provincial mid-year population was included as a log-offset. Incidence rate ratios (IRRs) and 95% confidence intervals were calculated, with Bonferroni adjustment for multiple comparisons.

For spatial analysis, the same model structure was stratified by Thailand's seven health regions: R1 (upper north), R2 (lower north), R3 (central), R4 (west), R5 (east), R6 (northeast), and R7 (south), allowing identification of regional heterogeneity in suppression and rebound intensity.

To analyze seasonal shifts, we used two-way ANOVA on monthly incidence counts aggregated across provinces. The model included fixed effects for calendar month (1–12), pandemic period (before [2014–2019], during [2020–2021], after [2022–2024]), and their interaction. Partial eta squared (η^2) and Bonferroni-adjusted p-values were used to evaluate effect sizes and significance. Monthly means and standard deviations (Mean±SD) were also computed to illustrate shifts in peak timing and seasonal amplitude. All statistical tests were two-sided with a significance threshold of α=0.05, adjusted where applicable.

Results

In Thailand, national incidence rates for pneumonia, pulmonary tuberculosis (TB), and influenza shifted markedly across the pre-COVID (2014–2019), during-COVID (2020–2021), and post-COVID (2022–2024) periods. Pneumonia incidence declined from 372.7±45.5 to 269.8±35.4 per 100,000 during COVID (−27%) and then rebounded to 469.5±125.3 post-COVID. Influenza declined from 278.4±175.6 to 101.9±120.2 during COVID and then rose sharply to 614.8±443.8 post-COVID, more than double pre-pandemic levels. In contrast, pulmonary TB rose modestly from 8.8±4.5 to 12.8±1.4 during COVID and remained stable at 12.6±1.9 thereafter. Monthly case counts followed similar trends: pneumonia decreased during COVID and rose post-COVID, TB increased slightly during COVID and remained stable, and influenza declined markedly during COVID and rose sharply afterward. Adjusted incidence rate ratios (IRRs) showed significant temporal changes for pneumonia and influenza, but not for pulmonary TB. For pneumonia, a significant decline was observed in the second pandemic year (IRR_D2=0.63; 95% CI: 0.41–0.96), followed by a significant increase post-COVID compared to the second pandemic year (IRR_PD2=1.97; 1.39–2.78). For influenza, IRRs dropped markedly in both pandemic years (IRR_D1=0.34; 0.22–0.53 and IRR_D2=0.04; 0.02–0.05), with a substantial and statistically significant rise after 2021 (IRR_PD2=34.36; 24.26–48.72). No significant differences were detected across any period for pulmonary TB. These patterns are consistent with the comparative estimates shown in Table 1.

Seasonal-trend decomposition (STL) revealed consistent pre-pandemic seasonality for all three diseases, followed by marked suppression during 2020–2021 and re-emergence after 2021, as shown in Figure 1.

For pneumonia, seasonal peaks typically occurred in September-October (+8,000 to +9,000 cases) and troughs in April-June (−4,000 to −5,000). The STL trend rose steadily until 2019, dipped during the pandemic, and rebounded post-COVID, reaching approximately 35,000–40,000 cases by late 2024. Residual spikes in late 2019 and late 2024 indicate deviations above expected seasonal baselines.

For pulmonary TB, a January peak (+650–700) and February–March trough (−200 to −300) were evident pre-COVID. The trend declined early in the series, increased through 2019, dropped during the pandemic, and stabilized around 400–500 cases/month post-2022. Residuals show positive outliers in January 2018–2019 and 2022–2023.

Influenza displayed a bimodal pattern pre-COVID (smaller peak in June–July, larger in September–October). The STL trend climbed to approximately 38,000 in 2019, collapsed during 2020–2021, and recovered sharply post-pandemic, reaching approximately 35,000 by mid-2024. The remainder component remained near zero during suppression but showed notable spikes in September 2023 and July 2024.

Two-way ANOVA (Month×Period) showed significant main effects of Month and Period for pneumonia and TB, but not for influenza seasonality, and no significant interactions for any disease (Table 2).

For pneumonia, both Month ($F(11, 96)=5.12$, $p<0.001$, $\eta p^2=0.37$) and Period ($F(2, 96)=36.10$, $p<0.001$, $\eta p^2=0.43$) were significant. September-October had the highest monthly means pre- and post-COVID (approximately 27,600 and 35,400 cases, respectively), while April-June remained the lowest (approximately 15,000 pre-COVID and 9,400 during COVID).

For pulmonary TB, Month ($F(11, 84)=4.76$, $p<0.001$, $\eta p^2=0.38$) and Period ($F(2, 84)=12.23$, $p<0.001$, $\eta p^2=0.23$) were also significant.

Table 1: Adjusted incidence rate ratios (IRRs) for pneumonia, pulmonary tuberculosis, and influenza across pre-pandemic, pandemic, and post-pandemic periods in Thailand

Disease	IRR_D1 (95% CI)	IRR_D2 (95% CI)	IRR_P (95% CI)	IRR_PD2 (95% CI)
Pneumonia	0.76 [0.50, 1.17]	0.63 [0.41, 0.96]*	1.24 [0.87, 1.75]	1.97 [1.39, 2.78]*
Pulmonary Tuberculosis	1.11 [0.72, 1.70]	0.85 [0.55, 1.31]	0.81 [0.56, 1.18]	0.95 [0.66, 1.38]
Influenza	0.34 [0.22, 0.53]*	0.04 [0.02, 0.05]*	1.19 [0.84, 1.69]	33.36 [24.26, 48.72]*

*p<0.05, Bonferroni-adjusted; IRR=Incidence Rate Ratio; CI=Confidence Interval; IRR_D1=incidence rate ratio of “Pandemic Year 1” vs “Pre-COVID”; IRR_D2=incidence rate ratio of “Pandemic Year 2” vs “Pre-COVID”; IRR_P=incidence rate ratio of “Post-COVID” vs “Pre-COVID”; IRR_PD2=incidence rate ratio of “Post-COVID” vs “Pandemic Year 2”

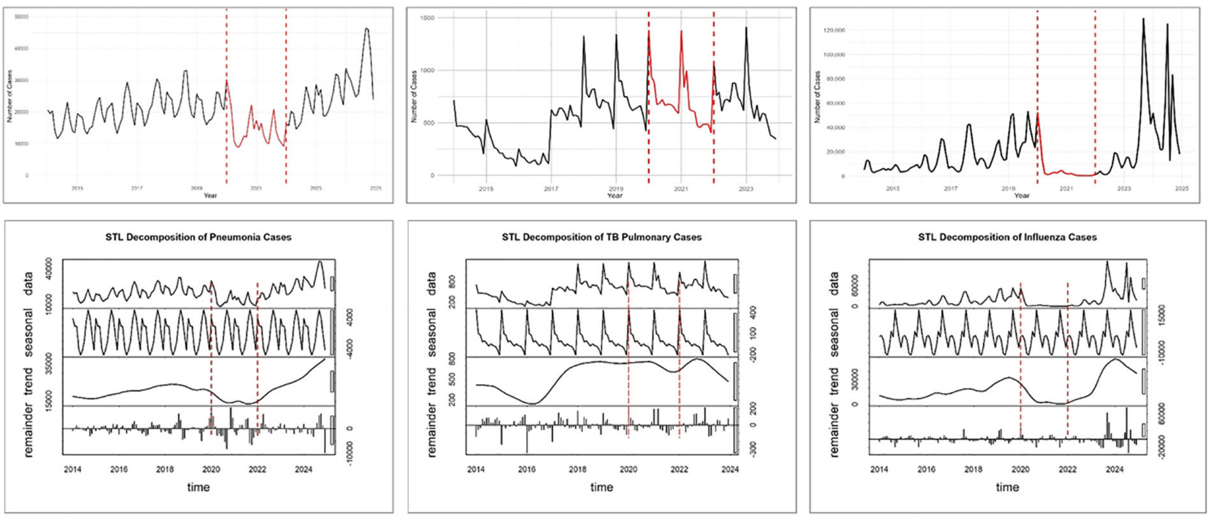

Figure 1: Monthly Case Trends and STL Decomposition of Pneumonia, Pulmonary TB, and Influenza in Thailand, 2014–2024. Source: Developed by the authors; STL: Seasonal-Trend Decomposition using Loess

Table 2: Two-Way ANOVA of pandemic period and seasonality effects on incidence of pneumonia, pulmonary tuberculosis, and influenza

Source	df	Pneumonia F (p) / ηp²	TB pulmonary F (p) / ηp²	Influenza F (p) / ηp²
MonthNum (Seasonality)	11	5.118 (<0.001) / 0.370	4.761 (<0.001) / 0.384	1.678 (0.090) / 0.161
Period (Pre/During/Post)	2	36.095 (<0.001) / 0.429	12.232 (<0.001) / 0.226	13.136 (<0.001) / 0.215
MonthNum×Period	22	0.898 (0.597) / 0.171	0.360 (0.996) / 0.086	1.134 (0.327) / 0.206

df=degrees of freedom; ηp²=partial eta squared; a. Corrected Model R^2 (Adjusted R^2): Pneumonia=0.631 (0.496); TB pulmonary=0.495 (0.285); Influenza=0.434 (0.228). b. N per cell (MonthNum×Period) – Pre / During / Post: • Pneumonia & Influenza: 6 / 2 / 3, • TB pulmonary: 6 / 2 / 2

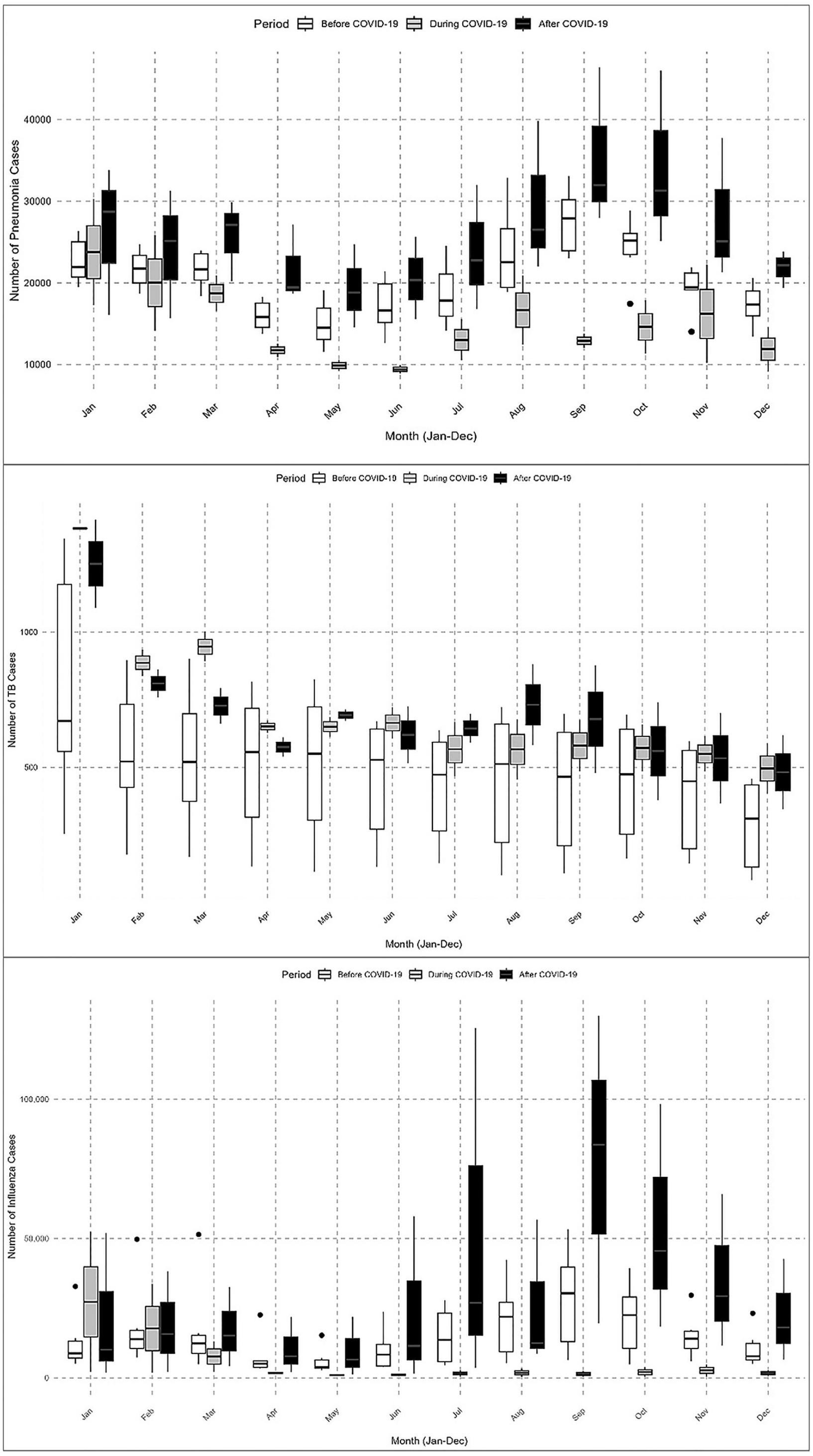

Figure 2: Monthly Seasonal Patterns of Pneumonia, Pulmonary TB, and Influenza in Thailand Before, During, and After COVID-19 (2014–2024). Source: Developed by the authors

January consistently had the highest values (ranging from approximately 801 to 1,381), with the lowest in June . For influenza, Period was significant ($F(2, 96)=13.14$, $p<0.001$, $\eta p^2=0.22$), but Month approached significance ($F(11, 96)=1.68$, $p=0.090$, $\eta p^2=0.16$). A new mid-year rise emerged post-COVID (June–July: approximately 23,600–52,000), alongside a strong September peak (approximately 77,700). Despite pandemic-related suppression, characteristic peak and trough months for each pathogen re-emerged in the post-COVID period, as reflected in the monthly distributions. Boxplots by calendar month further illustrate these patterns, highlighting seasonal suppression during 2020–2021 and resurgence thereafter for each disease (Figure 2).

Across Thailand's 77 provinces, visual inspection of annual choropleth maps (Figure 3) revealed three consistent spatial patterns across all three diseases: (a) persistent high-incidence hotspots before COVID, (b) widespread suppression during 2020–2021, and (c) regionally uneven rebounds after 2022

For pneumonia, pre-COVID hotspots were concentrated in northeastern and northern provinces, such as Si Sa Ket, Chiang Rai, and Mae Hong Son, which recorded some of the highest incidence rates nationwide. In 2021, incidence declined most in lower northern Thailand (R2: IRR=0.52; 95% CI: 0.08–3.35), with marked suppression observed in provinces such as Uttaradit and Phitsanulok, while eastern Thailand (R5) showed a more modest decline (IRR=0.85; 0.11–6.53), exemplified by Chanthaburi. By 2022–2024, post-COVID IRRs exceeded pre-COVID levels in some regions, most notably in central Thailand (R3: IRR=1.43; 0.46–4.47), with increases evident in Ang Thong and Chai Nat, as well as in southern Thailand (R7: IRR=1.43; 0.44–4.66), including Songkhla. Meanwhile, incidence remained low in upper northern Thailand (R1: IRR=0.33; 0.06–1.75).

For pulmonary TB, pre-COVID hotspots (2014–2019) were concentrated in provinces with the highest mean incidence, specifically Prachin Buri (52.6 per 100 000), Nong Khai (32.1), and Prachuap Khiri Khan (31.8). Incidence then remained relatively stable in early 2020 (R3: IRR=1.11; 0.72–1.70; R6: IRR=1.08; 0.45–2.59), with these hotspots, particularly Prachin Buri and Nong Khai, continuing to report elevated rates. In 2021, incidence declined most in western Thailand (R4: IRR=0.62; 0.09–4.44), exemplified by provincial drops in Kanchanaburi (Pre–During drop ~1.2 per 100 000) and Ratchaburi (~0.4). By 2022–2023, incidence partially recovered, with IRRs rising above pre-pandemic levels in lower northern Thailand (R2: IRR=1.64; 0.53–5.04) and western Thailand (R4: IRR=0.49; 0.09–2.62), driven by rebounds in Kamphaeng Phet (+11.4) and Phitsanulok (+10.0).

For influenza, pre-COVID hotspots (2014–2019) were concentrated in provinces with the highest mean incidence, including Bangkok (822.7 per 100 000), Rayong (715.4), Chiang Mai (657.2), Chanthaburi (506.0), and Nakhon Pathom (498.0). Incidence then fell sharply in 2020 across all regions (e.g., R3: IRR=0.29; 95% CI: 0.11–0.81; R6: IRR=0.43; 0.18–1.03), and nearly collapsed in 2021 (IRRs ~ 0.01–0.05) in these previously high-incidence areas.

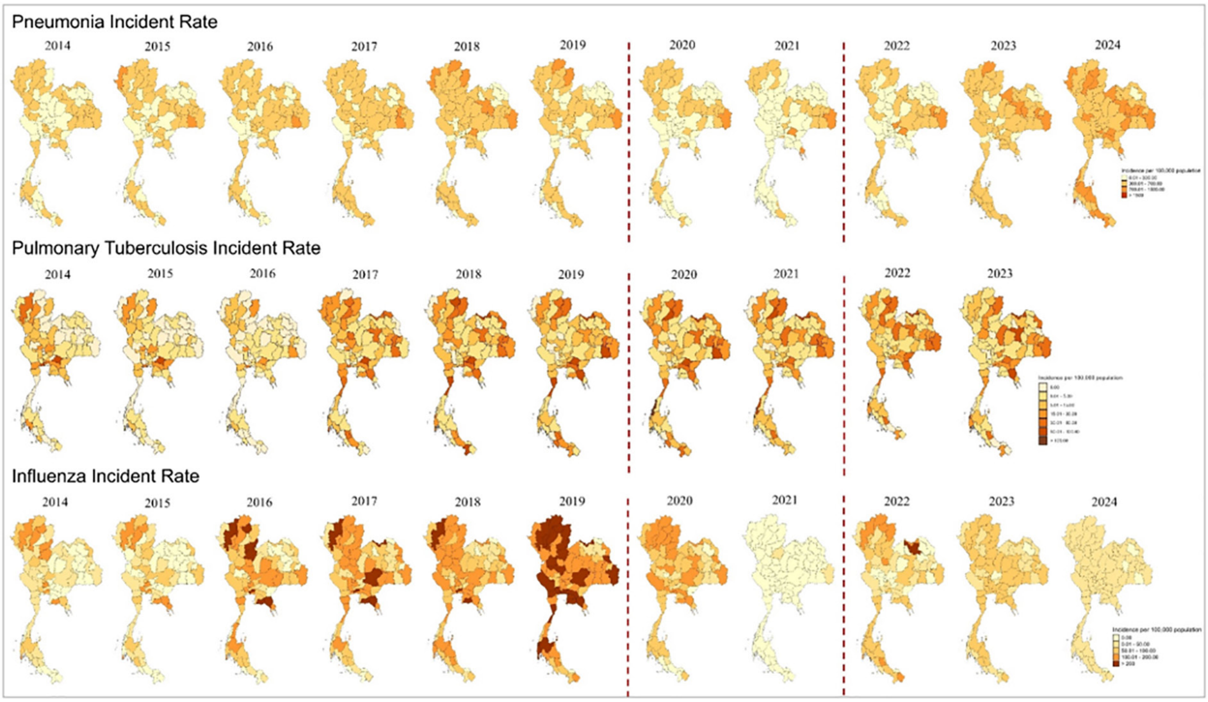

Figure 3: Annual Provincial Incidence Rates of Pneumonia, Pulmonary TB, and Influenza in Thailand, (2014–2024). Source: Developed by the authors

By 2022–2024, post-pandemic rebounds were most pronounced in central Thailand (R3: IRR=1.17; 0.53–2.60), exemplified by Bangkok (+1401.9) and Chachoengsao (+1061.0), and in southern Thailand (R7: IRR=1.96; 0.86–4.48), particularly Phuket (+1632.4) and Phatthalung (+1032.6). These patterns were consistent with the darkest choropleth shading in 2023–2024.

Discussion

This study demonstrates how the COVID-19 pandemic reshaped respiratory disease dynamics in Thailand across three key dimensions: time, geography, and seasonality. During the pandemic, reported cases of pneumonia, pulmonary tuberculosis (TB), and influenza declined substantially, followed by heterogeneous patterns of resurgence. These findings align with international literature documenting the indirect effects of non-pharmaceutical interventions (NPIs) on respiratory disease transmission.[7, 23-25]

Influenza experienced the most dramatic suppression, with monthly incidence falling to near zero during several months in 2020–2021. Overall reductions of 66% and 96% in the first and second pandemic years ($p<0.05$) correspond with the effects of NPIs such as mask mandates, school closures, and travel restrictions.[26, 27] These declines mirror patterns reported in Japan, Korea, and global surveillance, where influenza positivity dropped by over 75%.[1, 7, 23] Predictive models suggest that disruptions to seasonal cycles extended suppression even beyond the active enforcement period.[28, 29] Following the easing of restrictions, incidence initially returned to pre-COVID levels without statistical significance ($p>0.05$) before surging more than 30-fold relative to the second pandemic year ($p<0.05$), paralleling off-season outbreaks in Australia and Europe.[10, 30] These observations support the “immunity debt” hypothesis, whereby reduced population-level exposure increases susceptibility to rebound epidemics.[31]

Pneumonia exhibited a more gradual response. A 37% reduction in the second pandemic year ($p<0.05$) was consistent with declines observed in high-income countries, including a 32% decrease in childhood pneumonia and 14% in adults,[32] as well as a 38% drop in non-COVID pneumonia hospitalizations in Switzerland.[3] Post-pandemic, pneumonia incidence rebounded beyond baseline levels, consistent with surges seen in northern China and across Europe–North America in late 2022.[33, 34] The return of suppressed pathogens, such as RSV, influenza, and Mycoplasma pneumoniae, likely contributed to these trends,[35] along with increased pediatric vulnerability and altered healthcare-seeking behaviors.[33, 36]

By contrast, pulmonary TB showed relative stability across all periods, with no statistically significant change. Temporary fluctuations likely stem from pandemic-related service disruptions, including reduced diagnostic capacity, treatment delays, and the redeployment of resources.[5, 6, 38] A slight increase observed in late 2022 may reflect reactivation, treatment interruptions, or delayed case detection. These trends highlight the importance of maintaining person-centered, equity-oriented TB services that can withstand public health emergencies.[16]

Geographic variation in disease incidence further underscored pathogen-specific patterns. Influenza incidence collapsed uniformly across Thai regions during 2020–2021 (IRRs 0.01–0.05, $p<0.05$), followed by spatially uneven rebounds, particularly in the central and southern provinces where post-pandemic increases did not reach statistical significance ($p>0.05$). These trends mirror global observations of influenza re-emergence after NPI relaxation[39] and suggest that even partial NPIs created regional immunity gaps.[40, 41] Spatial clustering was concentrated in major urban areas such as Bangkok and Chiang Mai, consistent with prior studies linking urban density, mobility, and health disparities to transmission risk.[20]

Pneumonia exhibited broader regional suppression during the pandemic, with IRRs ranging from 0.52 to 0.85 across provinces ($p<0.05$). However, the rebound was uneven: the central and southern regions surpassed pre-COVID levels, while upper northern provinces remained below baseline ($p>0.05$). Environmental risk factors, such as elevated $PM_{2.5}$ levels in industrial and urban zones, have been associated with pneumonia burden,[19, 42] and pandemic-era air quality improvements may have reduced risk. Additionally, service disruptions likely affected pediatric and routine pneumonia care.[3, 43] In northern Thailand, prolonged mobility restrictions and healthcare access barriers may have delayed resurgence despite sustained environmental risk.

Spatial patterns for TB remained largely unchanged. Regional IRRs remained around 1 during the pandemic and ranged from 0.49 to 1.64 post-pandemic, with no statistically significant fluctuations. TB incidence remained concentrated in persistent localized clusters, consistent with its chronic nature and low transmissibility.[44] Nevertheless, variation in service delivery, including uneven adoption of bidirectional screening and targeted management in high-burden areas, may have contributed to regional disparities.[5, 16, 45-47] These findings reinforce the importance of localized service resilience and equitable access to TB care.

Seasonal analysis showed that despite dramatic case suppression during the pandemic, the core timing of seasonal peaks remained remarkably stable. For influenza, a pre-COVID September peak and April–May trough persisted through the pandemic, albeit with suppressed magnitude.[28, 31, 48] Post-pandemic patterns revealed an atypical mid-year surge and an intensified September peak, echoing unseasonal outbreaks and reinforcing the relevance of immunity debt.[10, 11, 31, 49]

Pneumonia followed a similar seasonal trajectory, with September–October peaks and April–June troughs re-emerging post-pandemic. Although incidence dropped during COVID-19, seasonality resumed quickly, particularly in conjunction with the return of RSV and influenza-associated lower respiratory tract infections.[15] In Thailand, these patterns are consistent with the rainy and winter seasons and suggest that pneumonia pathogens, especially viral agents, can re-establish seasonal rhythms once transmission conditions normalize.[4, 34, 50]

Pulmonary TB displayed the most stable seasonal pattern, maintaining late winter to spring peaks (January–May) and mid-year troughs across all periods. This consistency has been documented across diverse climates, including the UK, Mongolia, and Thailand.[51-53] Two-way ANOVA and STL decomposition confirmed Month and Period effects ($p<0.001$), with no significant interaction ($p=0.996$). The resilience of TB's seasonal structure, even under diagnostic and reporting constraints, underscores the influence of long-term epidemiological and climatic drivers.[54-58]

This study has several limitations. First, the use of aggregated surveillance data limited our ability to examine individual-level factors such as age, comorbidities, or vaccination status, which may have influenced observed trends. Second, reliance on R506 national surveillance data may have introduced underreporting or misclassification, particularly during periods of healthcare disruption and changes in healthcare-seeking behavior. Third, although spatial patterns were assessed using regional IRRs and choropleth maps, no formal spatial autocorrelation statistics (e.g., Moran's I) were applied, and broad regional groupings may have masked local heterogeneity. Fourth, fixed definitions of pandemic periods by calendar year may not fully reflect epidemiologic or policy transitions. Lastly, seasonal analyses may have been affected by changes in testing practices and overlapping clinical presentations of respiratory infections. Despite these limitations, the study offers a comprehensive analysis of how COVID-19 and related control measures reshaped respiratory disease patterns across time, space, and season in Thailand.

Conclusion

This study demonstrates that the COVID-19 pandemic reshaped respiratory disease patterns in Thailand in pathogen-specific ways. Influenza and pneumonia declined sharply during 2020–2021, followed by significant rebounds and altered seasonal peaks, while pulmonary tuberculosis remained stable, reflecting its chronic course and resilience to short-term disruption. Spatial analyses showed uneven recovery across regions, with rebounds concentrated in certain urbanized provinces. Seasonal patterns largely re-emerged after 2021. These findings underscore the need for adaptive, pathogen-specific surveillance systems. Public health strategies should ensure continuity of TB services, strengthen early warning for viral surges, and incorporate spatial and environmental data into planning to enhance preparedness for future respiratory disease disruptions.

Authors' Contribution

PSI contributed to the study design, performed the statistical analyses, and drafted the manuscript. PT conceived and supervised the study, developed the conceptual framework, led the methodological design and interpretation of the findings, and coordinated the overall manuscript development. PhS contributed to data acquisition and provided contextual interpretation of the results. All authors critically reviewed and approved the final version of the manuscript.

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Conflict of Interest

The authors declare no conflict of interest.

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