

Analysis of spatial-temporal distribution and influencing factors of pulmonary tuberculosis in Mainland China based on geographic information system, 2014-2023

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Abstract

Objective

To analyze the spatiotemporal trends and factors influencing of pulmonary tuberculosis (PTB) in Mainland China from 2014 to 2023, and to guide prevention and control strategies.

Methods

Analyze PTB incidence and mortality data from 31 regions in Mainland China (2014–2023). ArcGIS 10.8 mapped incidence distribution and performed spatial autocorrelation analysis. Data on medical institutions, health professionals, health expenditure, per capita Gross Domestic Product (PCGDP), illiteracy rate, temperature, humidity, precipitation, and sunshine duration were collected for Spearman rank correlation analysis.

Results

From 2014 to 2023, Mainland China's average annual PTB incidence was 54.18 per 100,000 people. Both incidence and mortality rates of PTB, along with its share among legally notifiable infectious diseases, have decreased. The global Moran's I index shows a positive spatial correlation for PTB incidence, while local analysis indicates clustering in northwest China. There is a notable positive spatial correlation between regional PCGDP and PTB incidence, and occasionally with illiteracy rates. In contrast, per capita health expenditure and the number of health technicians per thousand people are negatively correlated with PTB incidence in certain years. The number of medical institutions per capita does not correlate with PTB cases. Among climatic factors, PTB incidence sometimes correlates positively with humidity, but not with temperature, precipitation, or sunshine duration.

Conclusion

PTB incidence and mortality in China generally declined from 2014 to 2023. Attention is needed for its spread in the northwest, and cases may cluster in economically developed, humid areas. Boosting health spending, increasing medical staff, and lowering illiteracy rates could help reduce PTB incidence.

Introductions

Pulmonary tuberculosis (PTB) is a chronic pulmonary infectious disease caused by *Mycobacterium tuberculosis* (Mtb)(1). As a global infectious disease, tuberculosis(TB) has long been the leading cause of death among single infectious diseases worldwide(2, 3). Against the backdrop of the HIV/AIDS pandemic, increasing drug resistance, latent infection, and subclinical tuberculosis, PTB has become a focus of attention(4–9). Although the global TB incidence growth rate has slowed down, the number of

TB patients continues to rise. In 2024, there were 10.7 million new TB cases globally, with an incidence rate of 131 per 100,000 population. Among these, 30 high-TB-burden countries accounted for 87% of the total global TB cases(10). Global studies have shown that TB incidence and spatial autocorrelation remain significant, and TB risk factors are geographically specific(11).

China faces a severe burden of PTB. The World Health Organization's "2025 Global Tuberculosis Report" indicates that China is one of the 30 high-TB-burden countries in the world, ranking fourth and accounting for 6.5% of the estimated global incidence(10). Among notifiable infectious diseases in China, TB ranks second in both incidence and mortality, with an average annual reported rate of approximately 62.10 per 100,000 population and a mortality rate of about 0.14 per 100,000 population. The incidence rate of PTB in China is highest in the western region, followed by the central region, and lowest in the eastern region (47.90 per 100,000 population)(12, 13). Although the incidence and mortality rates have decreased significantly over the past few decades, reflecting the effectiveness of TB prevention and control strategies implemented in various periods, a high burden still persists in certain regions and populations(14, 15). To achieve the goals of the WHO's "End TB Strategy" by 2035, more rapid efforts are needed(16). Multiple challenges hinder TB prevention and control in China, including diverse transmission routes, heterogeneous TB distribution, multidrug-resistant tuberculosis (MDR-TB), extensively drug-resistant tuberculosis (XDR-TB), inadequate detection and treatment, and economic burdens(17–20). Therefore, studying the spatial distribution characteristics and influencing factors of PTB is crucial for formulating targeted strategies.

PTB cases in China exhibit obvious spatial clustering geographically. Its occurrence, development, and prevalence are spatial phenomena with interaction and diffusion. Spatial analysis can provide insights into the geographical distribution, clusters, and risk factors of PTB(21). PTB incidence in China shows a typical regional distribution pattern of being high in the west and low in the east, with significant differences among regions, and the epidemic situation remains severe in some areas(22, 23). Studies have shown that TB incidence is associated with various factors, including climatic conditions, population density, migration patterns of mobile populations, and economic development level(24–27). In addition, factors such as poverty, overcrowded living conditions, limited access to quality healthcare, malnutrition, alcohol dependence, and the increasing prevalence of comorbidities including AIDS, diabetes, and tobacco and drug abuse have greatly exacerbated TB transmission and deterioration, and increased the difficulty of effective management(9, 28–30). Differences in these factors lead to variations in TB incidence across regions, emphasizing the need to consider regional factors when formulating TB prevention and control strategies(31, 32).

PTB prevention and control strategies need to integrate spatiotemporal dynamic changes to more effectively allocate resources and formulate policies(33). In-depth analysis of the spatial distribution and influencing factors of PTB can provide strong data support for governments and public health institutions to achieve more effective PTB prevention and control(22, 34). Systematic analysis of its spatial distribution patterns and spatiotemporal dynamic changes is of great significance for identifying key areas and implementing precise prevention and control. Based on registered PTB case data in

mainland China from 2014 to 2023, this study used spatial autocorrelation analysis to explore the epidemiological characteristics and spatiotemporal clustering of PTB, and analyzed potential factors associated with PTB incidence, aiming to provide a basis for formulating targeted PTB prevention and control strategies and reference for similar studies.

Materials and Methods

Data Sources

Data on TB and other infectious diseases from 2014 to 2017 were obtained from the "China Health and Family Planning Statistical Yearbook", and data from 2018 to 2023 were sourced from the "China Health Statistics Yearbook". These data include incidence and mortality data of various notifiable infectious diseases in 31 provinces, autonomous regions, and municipalities in Mainland China (excluding Taiwan, Hong Kong, and Macao). A unique identifier was assigned to each province, autonomous region, and municipality directly under the Central Government to establish a spatial analysis attribute database. Using unified administrative division codes as continuous fields, ArcGIS was used to link the disease incidence rate of each province, autonomous region, and municipality directly under the Central Government with the national provincial geographic database to map spatial distribution. GeoDa software was used to define spatial weight matrices, form adjacency matrix relationships, and conduct spatial autocorrelation analysis. The division of eastern, central, and western regions followed the standards of the National Bureau of Statistics. Influencing factors, including the number of medical institutions per 10,000 population, number of health technical personnel per 1,000 population, per capita health expenditure (yuan), per capita gross domestic product (PCGDP, unit: 10,000 yuan), illiteracy rate (%), average temperature (°C), relative humidity (%), precipitation (mm), and sunshine duration (h) from 2014 to 2023, were all obtained from the "China Statistical Yearbook".

Global Spatial Autocorrelation Analysis

The Moran's I value was used to evaluate the spatial clustering of TB incidence in China, and the Monte Carlo simulation method was employed to test its significance. The Moran's I value ranges from -1 to 1 : a value > 0 indicates a positive correlation, and the closer it is to 1 , the more clustered the distribution; a value < 0 indicates a negative correlation, and the closer it is to -1 , the more dispersed the distribution; a value of 0 indicates a random spatial distribution with no spatial autocorrelation. GeoDa software was used for the analysis. The formula for calculating the Moran's I index is as follows(35):

$$I = \frac{n \sum_{i=1}^n \sum_{j=1}^n v_{ij} (x_i - \mu)(x_j - \mu)}{\sum_{i=1}^n \sum_{j=1}^n v_{ij} \sum_{i=1}^n (x_i - \mu)^2}$$

Where x_i and x_j represent the attribute values (e.g., incidence rate) of region i and region j , respectively; μ represents the mean of the attributes of all spatial units; v_{ij} represents the spatial weight between feature i and feature j ; and n represents the total number of spatial units.

Local Spatial Autocorrelation Analysis

Local spatial autocorrelation analysis typically presents four association patterns: high-high clustering (high-incidence areas surrounded by similar areas), high-low clustering (high-incidence areas surrounded by low-incidence areas), low-high clustering (low-incidence areas surrounded by high-incidence areas), and low-low clustering (low-incidence areas located among similar areas). Among these, high-high clustering and low-low clustering are positive spatial correlation patterns, indicating that the disease incidence in local areas is either equally high or equally low as that in adjacent areas. High-low clustering and low-high clustering are negative spatial correlation patterns, indicating that the attribute values of local areas are different from those of adjacent areas. These classifications help understand the spatial dynamic characteristics of TB incidence and enable more effective formulation of targeted intervention measures.

The formula for calculating the local Moran's I index is as follows:

$$I_i = \frac{n(x_i - \mu) \sum_j (x_j - \mu)}{\sum_j (x_i - \mu)^2}$$

Where x_i and x_j represent the attribute values (e.g., incidence rate) of region i and region j , respectively; μ represents the mean of the attributes of all spatial units.

Spearman Rank Correlation Analysis

Spearman rank correlation analysis was performed between the annual TB incidence rate of 31 provinces, autonomous regions, and municipalities in Mainland China and the number of medical institutions per 10,000 population, number of health technical personnel per 1,000 population, per capita health expenditure, PCGDP, illiteracy rate, average temperature, relative humidity, precipitation, and sunshine duration to observe the correlation between PTB incidence and the aforementioned factors.

Statistical Analysis

Excel 2010 was used to create raw data and compile tables summarizing the number of cases, incidence rate, and mortality rate of TB and other infectious diseases. SPSS software was used for Spearman correlation analysis. ArcGIS 10.8 and GeoDa 1.12 were used for spatial analysis to calculate the Moran's I value, Z value, and P value, respectively. A P value < 0.05 was considered statistically significant.

Results

The changing trend of PTB

From 2014 to 2023, PTB ranked second in terms of incidence rate among more than 20 notifiable infectious diseases in China for 10 consecutive years (Fig. 1A), while its mortality rate fluctuated between the second and third positions (Fig. 1B). In 2020, due to the second-highest mortality rate of COVID-19, PTB mortality ranked third for the first time. In 2023, the proportion of PTB mortality ranked third among more than 20 notifiable infectious diseases in China, following viral hepatitis with a certain margin. Specifically, the proportion of PTB incidence among more than 20 notifiable infectious diseases in China decreased from 28.91% in 2014 to 21.95% in 2023 (Fig. 1A), while the proportion of mortality decreased from 13.95% in 2014 to 8.06% in 2023 (Fig. 1B). Despite the decreasing trends in the proportions of PTB incidence and mortality among notifiable infectious diseases in China, PTB still ranks among the top three in terms of disease burden. Given China's large population base, PTB remains one of the high-burden infectious diseases in China.

The trend of incidence and mortality rates of PTB over time

We collected data on PTB incidence and mortality in China over the past 10 years (2014–2023). A total of 7,507,955 registered PTB cases were reported in mainland China from 2014 to 2023, with an average annual registered incidence rate of 54.1776 per 100,000 population. The lowest incidence rate was recorded in 2022 (39.7596 per 100,000 population), and the highest in 2014 (65.6288 per 100,000 population). In 2023, the number of new PTB cases was 613,091, an increase of 52,244 cases (9.315%) compared with 560,847 cases in 2022. The incidence rate of new PTB infections decreased from 65.6288 per 100,000 population in 2014 to 43.4893 per 100,000 population in 2023. The registered incidence rate of PTB in mainland China showed an overall downward trend from 2014 to 2023, with an upward trend in 2023 (Table 1, Supplementary Fig. 1A). In addition, the PTB-related mortality rate in China from 2014 to 2023 showed a trend of first increasing, then decreasing, and then increasing again. The highest PTB mortality rate in China was recorded in 2018 (0.2266 per 100,000 population), followed

by a downward trend, reaching the lowest in 2021 (0.1251 per 100,000 population), and then rebounding to 0.1537 per 100,000 population in 2023 (Table 1, Supplementary Fig. 1B).

Table 1
Trends of incidence and mortality of PTB in China from 2014 to 2023.

Year	Incident cases	Morbidity (1/100000)	Death cases	Mortality (1/100000)
2014	889381	65.6288	2240	0.1653
2015	864015	63.4155	2280	0.1673
2016	836236	61.0042	2465	0.1798
2017	835193	60.5283	2823	0.2046
2018	823342	59.2717	3149	0.2266
2019	775764	55.5491	2990	0.2141
2020	670538	47.7644	1919	0.1366
2021	639548	45.3651	1763	0.1251
2022	560847	39.7596	2205	0.1563
2023	613091	43.4893	2167	0.1537

Spatial distribution analysis of PTB incidence rate in China over 2014–2023

To demonstrate regional differences in PTB incidence, we used ArcGIS to map the spatial distribution of TB incidence (per 100,000 residents) across 31 provinces, autonomous regions, and municipalities in Mainland China(Fig. 2). From 2014 to 2023, the average reported PTB incidence rate was highest in the western region (78.69/100,000), followed by the central region (55.02/100,000) and the eastern region (40.94/100,000 population). The western and central regions had higher incidence rates than the national average (54.18/100,000 population), while the eastern region had a lower rate. For better analysis, the period 2014–2023 was divided into two phases: 2014–2019 and 2020–2023. From the spatial distribution map, it can be seen that PTB incidence in China remained generally high from 2014 to 2019, decreased significantly after 2020, but rebounded after 2023. Regarding the spatial zoning characteristics of incidence rates, the top 4 regions with the highest registered PTB incidence rates in China from 2014 to 2019 were Xinjiang (204.04/100,000), Tibet (158.32/100,000), Qinghai (127.03/100,000), and Guizhou (122.02/100,000). From 2020 to 2023, the provinces with the highest PTB incidence rates were Tibet (122.84/100,000), Xinjiang (89.79/100,000 population), Guizhou (84.50/100,000), and Qinghai (84.23/100,000). Although the high-incidence areas did not change, the incidence rates in these four regions generally showed a downward trend. Nationwide, the eastern coastal and North China regions had the lowest PTB incidence rates. From 2014 to 2019, the top 4 regions with the lowest registered PTB incidence rates in China were Tianjin (21.66/100,000), Shanghai (27.29 per 100,000), Shandong (31.02/100,000), and Beijing (32.00/100,000). From 2020 to 2023, the

lowest incidence rates were recorded in Shanghai (19.73/100,000), Tianjin (22.48/100,000), Shandong (22.63/100,000), and Jiangsu (25.47/100,000).

Global spatial autocorrelation analysis of PTB incidence rate in China over 2014–2023

Taking 31 provinces, autonomous regions, and municipalities in Mainland China as spatial units, global spatial autocorrelation analysis was conducted to evaluate the spatial clustering and random distribution trends of PTB in China. The Moran's *I* value, *Z* value, and *P* value were obtained (Table 2). The results showed that the spatial distribution was non-random, presenting a positive spatial correlation with a Moran's *I* value > 0, absolute *Z* value > 1.96, and *P* < 0.05, which was statistically significant. This indicates that there was a statistically significant positive spatial correlation in PTB incidence in mainland China from 2014 to 2023, showing a spatially clustered distribution. Similarly, during the two study periods (2014–2019 and 2020–2023), the incidence rate of new PTB infections also showed a positive spatial correlation distribution.

Table 2 Global spatial autocorrelation analysis of incidence rate of PTB in China from 2014 to 2023.			
Year	Moran's <i>I</i>	<i>Z</i> Score	<i>P</i> Value
2014	0.359	5.245	< 0.001
2015	0.338	4.968	< 0.001
2016	0.314	4.680	< 0.001
2017	0.309	4.688	< 0.001
2018	0.206	3.695	< 0.001
2019	0.288	4.362	< 0.001
2020	0.336	4.975	< 0.001
2021	0.341	5.046	< 0.001
2022	0.421	5.910	< 0.001
2023	0.406	5.726	< 0.001
2014–2019	0.302	4.608	< 0.001
2020–2023	0.380	5.461	< 0.001

Local spatial autocorrelation analysis of PTB incidence rate in China over 2014–2023

The results of global spatial autocorrelation analysis indicated a positive spatial correlation in PTB distribution, so further local spatial autocorrelation analysis was conducted to identify clustered areas. Figure 3 shows the LISA spatial cluster map generated by local spatial autocorrelation analysis. From

2014 to 2023, the local spatial autocorrelation of PTB incidence in mainland China presented two cluster patterns: high-high and low-low. The overall trend was similar, with high-high clustering in the northwest region and low-low clustering in the North China region. From 2014 to 2019, provinces with high-high clustering of PTB incidence were mainly concentrated in Xinjiang Uygur Autonomous Region and Tibet Autonomous Region, while low-low clustering areas were distributed in Inner Mongolia Autonomous Region, Liaoning Province, Hebei Province, Tianjin Municipality, Shanxi Province, Shaanxi Province, Shandong Province, Henan Province, Jiangsu Province, Anhui Province, and Zhejiang Province. From 2020 to 2023, provinces with high-high clustering of PTB incidence were concentrated in Xinjiang Uygur Autonomous Region, Tibet Autonomous Region, Yunnan Province, and Guangxi Zhuang Autonomous Region, and the low-low clustering areas were the same as those in 2014–2019 (Fig. 3).

Correlation analysis of some factors and the PTB incidence rate in China over 2014–2023

The overall level of medical and health resource allocation in Chinese hospitals showed a steady upward trend, with the largest increase in 2022–2023 (Supplementary Fig. 2A), and the number of health technical personnel per 1,000 population increased steadily year by year (Supplementary Fig. 2B). Health expenditure, including government expenditure, social expenditure, and personal expenditure, all showed an upward trend (Supplementary Fig. 2C). In terms of economic level, the annual GDP showed an increasing trend year by year (Supplementary Fig. 2D). The national illiteracy rate began to decline in 2015, reached the lowest in 2021, and then stabilized at a relatively stable level, showing an overall downward trend (Supplementary Fig. 2E).

Focusing on provinces, municipalities directly under the Central Government, and autonomous regions, we found that from 2014 to 2023, the number of medical institutions per 10,000 population showed an increasing trend in most regions of China, while only three regions showed a slow decrease: Tibet (-9.60%), Qinghai (-4.20%), and Shanxi (-2.31%), all of which are western provinces (Fig. 4A). The average number of health technical personnel was highest in the eastern region, but the growth rate in the central and western regions was higher than that in the eastern region. Despite being economically developed provinces in the eastern region, Guangdong and Fujian had a lower allocation of health technical personnel than the national average (Fig. 4B). The per capita health expenditure of each province, municipality directly under the Central Government, and autonomous region increased by nearly 1.5 times over 10 years, with an average annual growth rate of over 10%, led by Shanghai and Tibet (Fig. 4C). Regarding the illiteracy rate, except for Gansu, the illiteracy rate in all other regions of the country showed a downward trend. Although Tibet had the highest reduction in illiteracy rate, it still had the highest average illiteracy rate (34.76%), followed by Qinghai and Guizhou (Fig. 4D). The absolute gap in PCGDP between the western and eastern regions remained large: 8 regions had a PCGDP $\geq$ 100,000 yuan, mainly concentrated in economically developed eastern coastal areas, while 6 regions had a PCGDP < 60,000 yuan, concentrated in the central, western, and northeastern regions, with Gansu being the most underdeveloped province (Fig. 4E).

To analyze the correlation between medical resources, economy, education, meteorological factors, and PTB incidence in various regions of China, Spearman rank correlation analysis was performed between the PTB incidence rate of each region from 2014 to 2023 and the average number of medical institutions, number of health technical personnel, health expenditure, per capita GDP, illiteracy rate, average temperature, relative humidity, precipitation, and sunshine duration. The results showed that there was no correlation between the PTB incidence rate and the average number of medical institutions in various provinces, municipalities directly under the Central Government, and autonomous regions of China in different years. However, a negative correlation was observed with the number of health technical personnel (2014, 2020–2023) and health expenditure (2014–2015) in some years (Supplementary table 3). The PTB incidence rate in various regions showed a strong positive correlation with per capita GDP in different years, and a positive correlation with the illiteracy rate in some years (2020, 2022, 2023) (Supplementary table 4). PTB incidence had no correlation with factors such as average temperature, precipitation, and sunshine duration, but showed a positive correlation with relative humidity in some years (2015, 2017) (Supplementary table 5).

Discussion

Based on 2014–2023 data, this study reveals the spatiotemporal evolution and influencing factors of PTB in mainland China. While Mainland China has achieved significant progress in PTB control, evidenced by a general declining trend in both incidence and mortality, notable challenges persist, characterized by distinct geographical disparities and the influence of socio-economic and environmental factors. Despite being below the global average, China remains the third highest TB burden country globally, following India and Indonesia (WHO, 2024)(36). From 2014 to 2023, the incidence of PTB in China declined by 33.7%, with notable reductions of 14.01% (2019–2020) and 12.4% (2021–2022). New cases peaked in 2014 and reached the lowest level in 2022, before a slight rebound in 2023. Mortality from PTB also consistently decreased. Among over 20 notifiable infectious diseases in China, PTB incidence consistently ranked second during this period, while its mortality fell below that of viral hepatitis for the first time in 2023, dropping to third place.

Spatio-temporal distribution analysis showed significant regional differences in the PTB epidemic in China. Overall, the reported incidence rate was relatively low in the eastern region and high in the western region. PTB incidence in China remained generally high from 2014 to 2019, decreased significantly after 2020, but rebounded after 2023. In the early stage of 2020–2023, measures such as home isolation and mask-wearing during the COVID-19 pandemic may have significantly reduced PTB transmission. However, the national PTB incidence rate rebounded again in 2023. Globally, 8.2 million new TB cases were registered and reported in 2023, reaching a record high(37), which is consistent with the upward trend of PTB in China. The reasons may be partly related to the backlog of PTB patients caused by delayed diagnosis and treatment due to COVID-19. On the other hand, it may be associated with the resumption of international exchanges and the reduction of epidemic prevention and control levels after the pandemic. In addition, the popularization of molecular biology diagnostic technology, the gradual improvement of the molecular laboratory network, and the increased allocation of departments

such as infectious diseases/infectious diseases/fever clinics after the pandemic may have improved the detection rate of PTB. The impact of the COVID-19 pandemic highlights the need to maintain effective TB diagnosis and treatment programs(38). From the analysis of PTB clustering areas, the incidence rate of PTB is higher in western regions such as Tibet and Xinjiang, while it is lower in North China and eastern coastal areas. Strengthening local prevention and control work in high-incidence areas of PTB and formulating strategies to strengthen PTB monitoring, diagnosis, and treatment are of guiding significance for reducing the PTB incidence rate.

PTB incidence may be affected by social or geographical factors such as economy, medical care, health expenditure, education, and climate. This difference is not unique to a certain region; similar distribution patterns have been observed in countries such as the United States(39), Brazil(40), and South Africa(41). Our study found a significant positive correlation between PTB incidence and regional PCGDP. Given the characteristics of PTB, such as a long incubation period and prolonged infectious period, spatial clusters do not always indicate active transmission, but may reflect the migration of high-risk populations between different regions(42, 43). The reason for the high TB incidence rate in areas with high PCGDP may be that economic development attracts population from high-incidence areas, concentrating and amplifying the risk factors for disease transmission and occurrence. Studies have found a significant spatial autocorrelation between PTB and internal migration(25). These mobile populations may have been latently infected with PTB in their places of origin, but developed the disease due to factors such as stress and overwork after entering new environments. In addition, the high medical level and strong diagnostic capabilities in developed areas enable these imported cases to be detected and reported more timely and accurately. This reminds us that when studying disease distribution, we should not only focus on geographical or economic boundaries but also pay attention to complex population migration patterns. Secondly, some studies have found that the prevalence of diabetes is higher in high-income countries, which may lead to an increase in PTB incidence in these regions(44).

We found that per capita health expenditure was negatively correlated with PTB incidence in some years. Increased health expenditure may affect vaccination coverage, effective public health monitoring and tracking, public health education, as well as more efficient and accessible diagnosis and treatment. A study in southwestern Ethiopia found that insufficient medical resources, such as a shortage of medical personnel, inadequate infrastructure, and lack of diagnostic equipment, severely hindered the detection and reporting of PTB cases(45). In low-income and lower-middle-income countries, a higher Human Development Index (HDI), social protection expenditure, TB case detection rate, and treatment success rate are associated with a lower TB incidence rate(46). However, similar to some high-income countries, despite high health expenditure, certain marginalized groups still face a high risk of PTB due to social inequality and uneven resource allocation(47). Similarly, we found that the number of health technical personnel per 1,000 population was negatively correlated with TB incidence in some years. A study in Xinjiang, China found that a low number of medical and health personnel is an important factor affecting TB incidence(48). More health technical personnel mean a stronger medical and health system, which helps achieve "early detection, early diagnosis, and early treatment" of PTB and reduce the number of new infections(49).

Cultural cognition and educational level are also important for the understanding of diseases, the timeliness of diagnosis and treatment, and the degree of attention paid. Studies have found that TB often affects people with low educational backgrounds(50). Our study found a negative correlation between the illiteracy rate and PTB incidence in some years. This indicates that the increase in the illiteracy rate partially affects PTB incidence. In areas with a high illiteracy rate, factors such as insufficient understanding of the disease, a tendency to believe in folk remedies or seek treatment from witch doctors, poor medical accessibility and treatment compliance, and poverty caused by backward knowledge may all affect the incidence of PTB. Given the partial spatial correlation between high illiteracy rate and high PTB incidence, consistent with relevant studies, we believe that the public's health literacy regarding PTB still needs to be improved, especially among the elderly, people with low educational backgrounds, and students(51).

Climatic factors also affect PTB incidence to a certain extent. A study in Nepal found that environmental factors such as land surface temperature, urbanization, and precipitation are significantly associated with the spatial distribution of TB(52). We found a partial positive correlation between humidity and PTB incidence in various regions, which is consistent with some domestic studies in China(34, 53, 54). PTB is transmitted from patients with active disease to uninfected individuals through small aerosol droplets containing *Mycobacterium tuberculosis* (usually 1 to 5 μm in diameter)(55). Moderately high humidity may help these droplets containing *Mycobacterium tuberculosis* maintain an appropriate size and weight, prolong their survival time, and increase the risk of transmission. Therefore, keeping the environment dry may help reduce the PTB incidence rate to a certain extent. In addition, our study found that TB incidence has no correlation with climatic factors such as temperature, precipitation, and sunshine duration. Although some studies have found that high temperatures can cause heat stress, thereby weakening the immune system and indirectly promoting the activation of latent PTB infection(56, 57), we did not find this correlation in the correlation analysis of PTB data in China.

By analyzing the spatiotemporal distribution characteristics and influencing factors of PTB in China from 2014 to 2023, this study provides reliable data support for further improving key prevention and control strategies. Spatiotemporal distribution patterns suggest that when formulating prevention and control plans, the specific conditions of various high-PTB-incidence areas should be fully considered. To effectively control PTB, comprehensive measures covering health, education, environment, and social security are necessary.

Limitations

First, variations in local monitoring quality could affect the accuracy of registered data used in this study. Second, this study uses a provincial - level aggregate data ecological design. It can't establish causal relationships between individual - level risk factors and PTB incidence, potentially causing ecological fallacy. Third, key PTB risk factors (e.g., population mobility, multi - drug - resistant tuberculosis prevalence, etc.) were not fully included in the correlation analysis, which may limit the comprehensiveness of identifying PTB spatial - temporal distribution drivers.

Conclusions

In summary, the registered incidence rate, mortality rate of PTB in China, and their proportions among all notifiable infectious diseases generally showed a downward trend from 2014 to 2023. The prevalence of PTB has spatiotemporal clustering characteristics, and Xinjiang Uygur Autonomous Region, Tibet Autonomous Region, and Yunnan Province are key PTB prevention and control areas. Affected by the resumption of opening up after the end of the COVID-19 pandemic, the PTB incidence rate rebounded in 2023. Correlation analysis indicated that increasing per capita health investment, expanding the number of per capita health personnel, and improving education to eliminate illiteracy may help reduce the PTB incidence rate to a certain extent, while per capita GDP and the number of medical institutions cannot predict the PTB incidence rate in a region. PTB incidence may be partially affected by climatic factors such as humidity, but has little relationship with other climatic factors such as temperature, precipitation, and sunshine duration. In conclusion, the results of this study emphasize the spatial differences in PTB incidence in China and their influencing factors. Controlling the PTB incidence rate requires formulating targeted public health strategies addressing environmental and socioeconomic factors.

Abbreviations

TB Tuberculosis

PTB Pulmonary tuberculosis

GDP Gross domestic product

PCGDP Per capita Gross Domestic Product³

AIDS Acquired Immunodeficiency Syndrome

RMB Renminbi

WHO World Health Organization

COVID-19 Coronavirus disease 2019

Declarations

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Author Contributions

Haibo Ding, Jiaofeng Huang: conceptualization, supervision, project administration, writing—review and editing. Xinzhu Xiao: conceptualization, resources, data curation, investigation, writing—original draft, writing—review and editing. Yuping Zhan: software, formal analysis, visualization, methodology, writing—original draft. Yunfei Chen: software, formal analysis, visualization, writing—review and editing. Qichao Fan: data curation, formal analysis, methodology, Junjin Liu: data curation, validation, investigation, methodology. All authors reviewed the manuscript.

Ethics approval and consent to participate

We declare that ethics approval and consent to participate is not applicable to this study.

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Conflict of Interest

The authors have no competing interests associated with this study to declare.

Data Availability

All the data generated or analyzed during this study are included in this manuscript.

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Figures

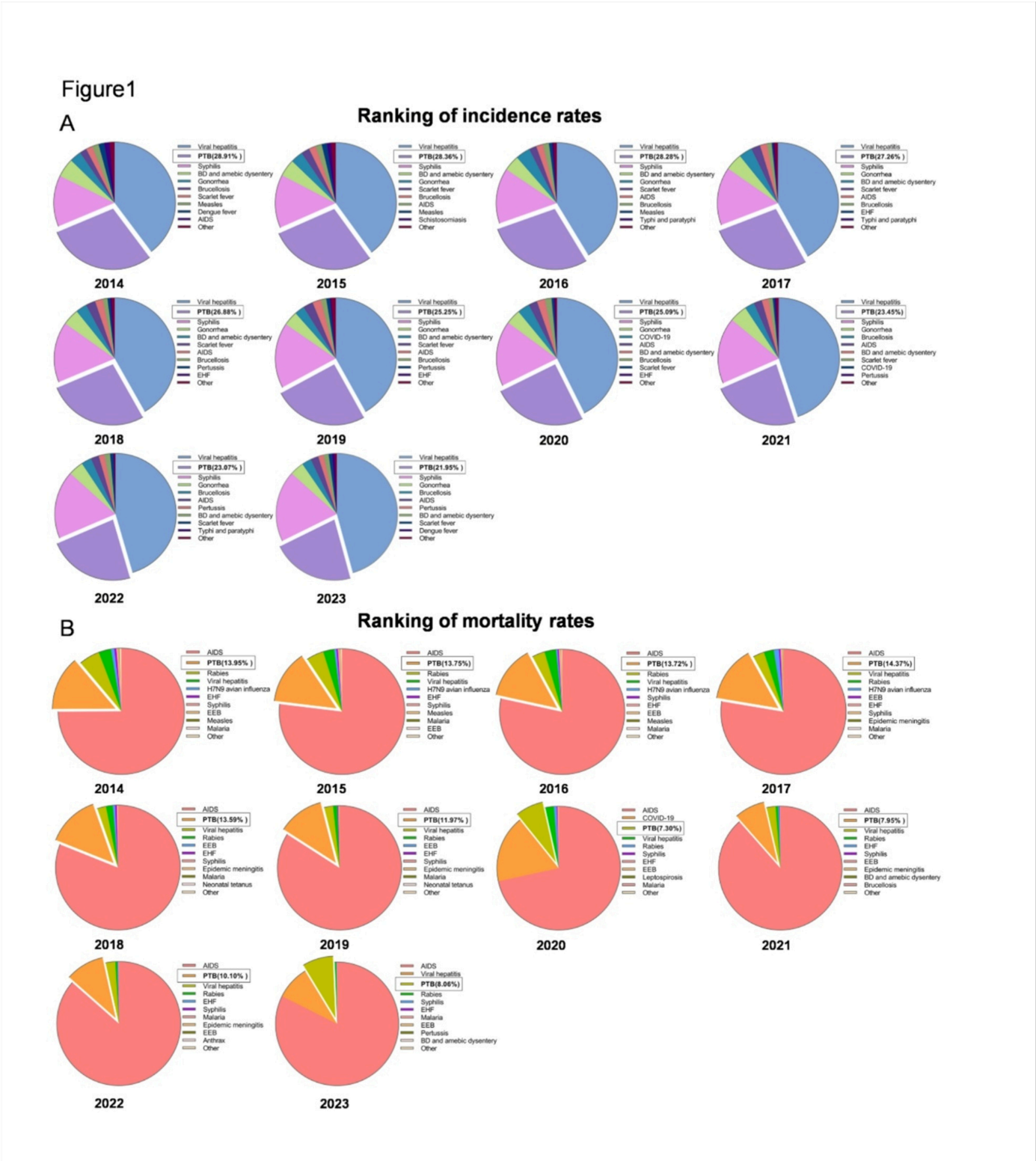


Figure 1

Ranking changes of the incidence and mortality rates of PTB among the legally reported infectious diseases in China from 2014 to 2023.

(A)Ranking changes of the incidence rates of PTB among the legally reported infectious diseases.
(B)Ranking changes of the mortality rates of PTB among the legally reported infectious diseases.
PTB,Pulmonary tuberculosis; BD,Bacillary dysentery; AIDS,Acquired Immunodeficiency Syndrome; EHF,
Epidemic hemorrhagic fever; COVID-19, Corona Virus Disease 2019; EEB, Epidemic encephalitis B.

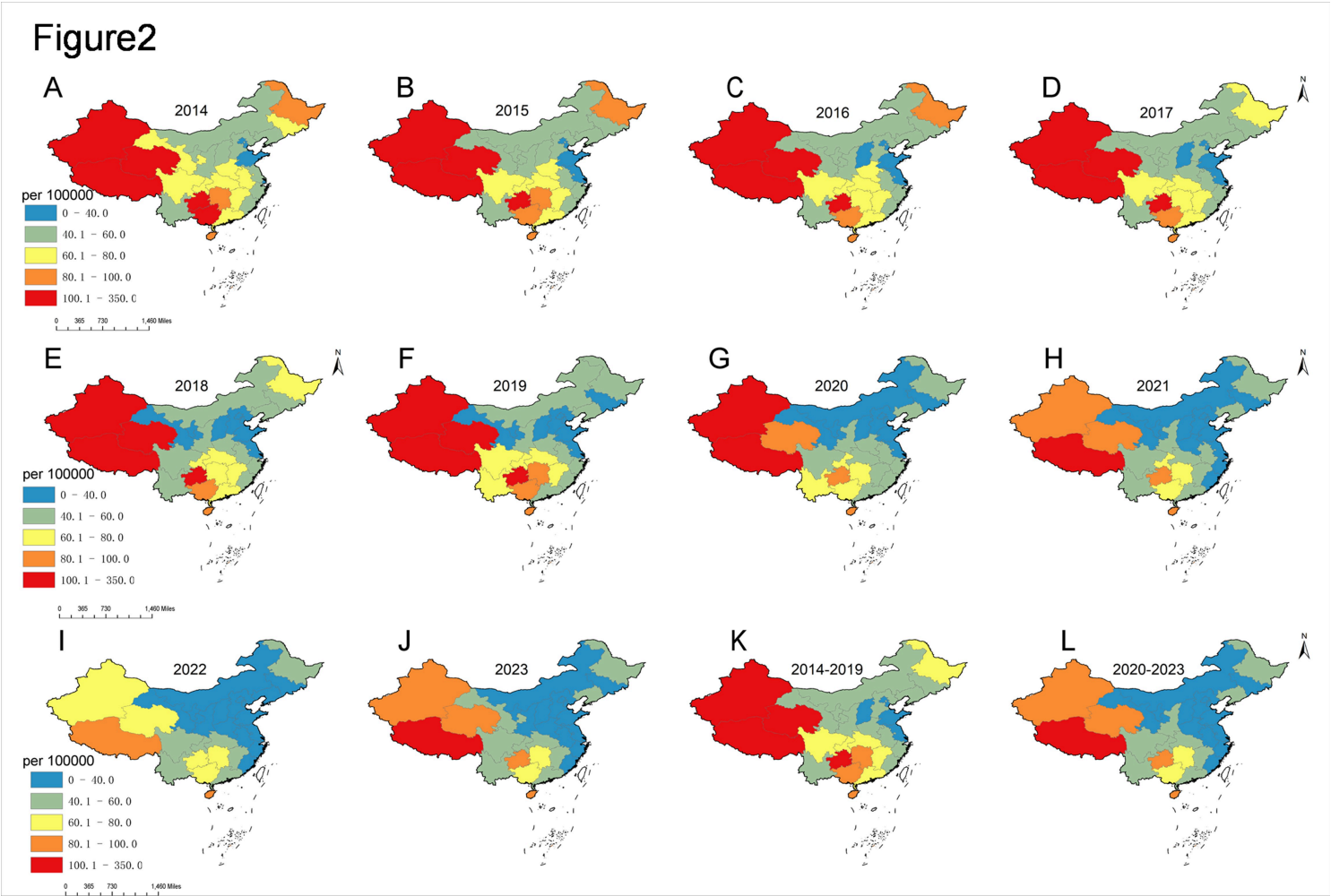


Figure 2
The spatial variation in temporal trends of PTB in China, 2014–2023.

Figure3

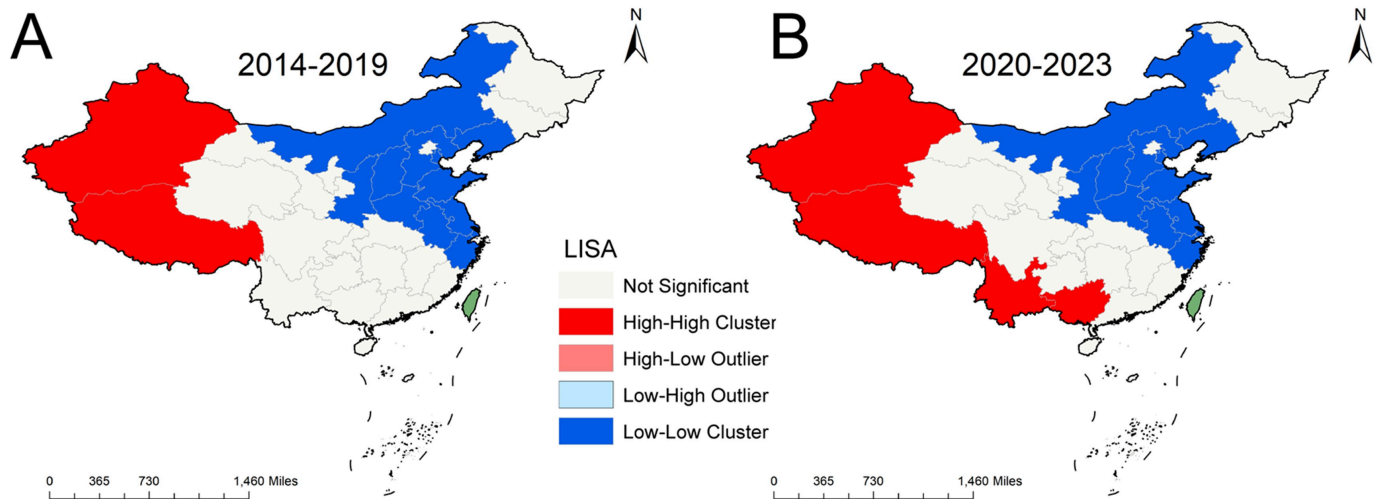


Figure 3

Local spatial autocorrelation analysis of the incidence of PTB in China,2014-2019 and 2020-2023.

(A) Local spatial autocorrelation analysis of the incidence of PTB in China,2014-2019. (B) Local spatial autocorrelation analysis of the incidence of PTB in China,2020-2023.

Figure4

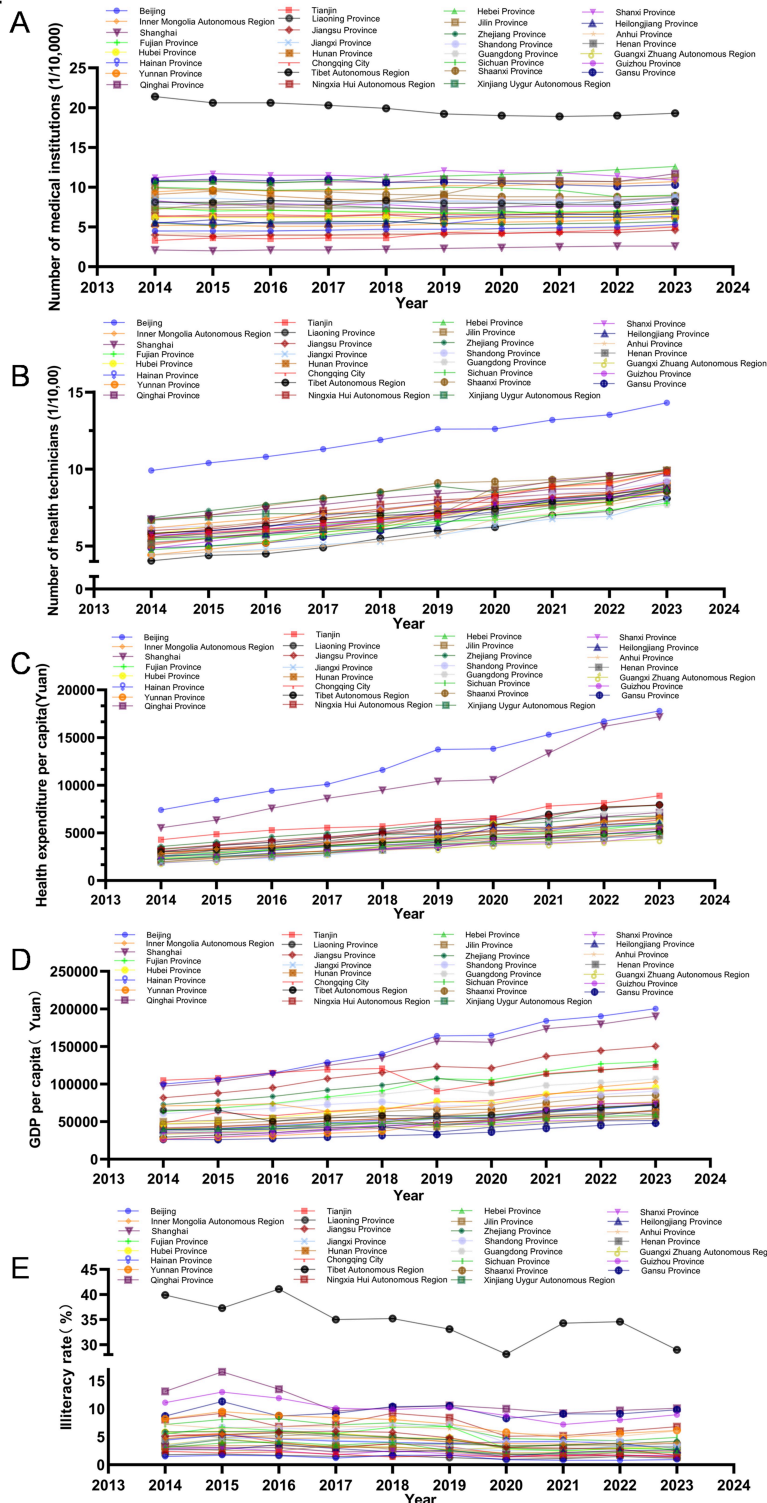


Figure 4

Trends of the number of medical institutions, health technicians, health expenditure, PCGDP and illiteracy rate in the China by region, 2014-2023.

(A) Trends of the number of medical institutions by region.(B) Trends of the number of health technicians by region.(C) Trends of health expenditure by region.(D) Trends of PCGDP.(E)Trends of

illiteracy rate by region.

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