

Spatio-Temporal Patterns and Distribution Characteristics of Human Brucellosis in Xinjiang, China, 2018–2024

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1 **Spatio-Temporal Patterns and Distribution Characteristics**
2 **of Human Brucellosis in Xinjiang, China, 2018–2024**

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18 **Abstract**

19 **Background:**Human brucellosis remains a significant public health concern in
20 Xinjiang, China, where spatial heterogeneity and complex ecological factors contribute
21 to its persistent burden. Understanding the spatiotemporal dynamics of the disease is
22 critical for optimizing prevention and control strategies.

Methods: The analyses included temporal trend assessment using the Theil–Sen slope estimator and Mann–Kendall trend test, global and local spatial autocorrelation analysis, hot spot analysis, and standard deviational ellipse analysis to characterize spatial distribution patterns and epidemiological features.

Results: The incidence of human brucellosis showed a significant overall upward trend despite interannual fluctuations, reaching a peak in 2023 and remaining at a relatively high level in 2024. Local spatial autocorrelation revealed persistent high–high clustering in northern and eastern Xinjiang and low–low clustering in southern Xinjiang. Hot spot analysis identified localized high-incidence areas with temporal variation, mainly concentrated along the northern slopes of the Tianshan Mountains, the Ili River Valley, and the Altay region. Standard deviational ellipse analysis indicated changes in spatial dispersion and directional distribution over time, while the weighted mean center remained in northern Xinjiang.

Conclusion: Human brucellosis in Xinjiang showed a significant overall upward trend and persistent spatial heterogeneity during 2018–2024, with hot spots mainly concentrated in northern Xinjiang. These findings support region-specific surveillance and targeted interventions for brucellosis prevention and control.

Keywords: human brucellosis; spatial epidemiology; GIS; disease surveillance; hot spot analysis; spatiotemporal distribution

Introduction

Human brucellosis is a zoonotic infectious disease caused by infection with *Brucella* spp., a genus of Gram-negative coccobacilli. Common animal hosts include livestock such as cattle, sheep, and pigs, as well as certain wild animals. Humans can become infected through direct contact with tissues from infected animals, consumption of unpasteurized dairy products or undercooked meat, and inhalation of aerosols containing the pathogen^(1,2). Clinical manifestations typically include fever, excessive sweating, fatigue, and arthralgia. If the disease becomes chronic, it may lead to complications such as hepatomegaly, arthritis, and spondylitis⁽³⁾. Brucellosis is endemic in many parts of the world, with relatively high incidence rates reported in livestock-producing regions such as the Mediterranean Basin, the Middle East, Central Asia, and Latin America^(4,5). In recent years, due to the expansion of animal husbandry and increased human mobility, the incidence of brucellosis has risen in certain areas⁽⁶⁾. According to the World Health Organization, approximately 500,000 new human cases are reported globally each year, indicating that brucellosis remains a significant public health challenge⁽⁷⁾.

The epidemiology of brucellosis exhibits a distinct seasonal pattern, primarily influenced by the reproductive cycles of livestock, human activities, and environmental factors⁽⁸⁾. Spring marks the peak breeding season for livestock such as sheep and cattle, during which animals are more likely to shed *Brucella* spp. while giving birth or nursing, thereby significantly increasing the risk of human infection⁽⁹⁾. Spring and summer also coincide with peak periods of livestock trade and migration, further facilitating

pathogen transmission⁽¹⁰⁾. Brucellosis also demonstrates notable spatial clustering. In China, high-incidence areas are predominantly located in the northern regions, extending westward from central and eastern Inner Mongolia to adjacent provinces including Heilongjiang, Liaoning, Hebei, and Shanxi⁽¹¹⁾. These regions are typically rural towns with economies based on animal husbandry or agriculture, where healthcare resources are relatively limited compared to urban areas, and the affected population is primarily composed of herders and farmers in pastoral and agricultural zones⁽¹²⁾.

The Xinjiang Center for Disease Control and Prevention, along with other relevant agencies, has actively conducted brucellosis surveillance, collecting and analyzing extensive data to monitor the dynamic trends of the epidemic. Statistics show that between 2018 and 2023, the incidence rate of human brucellosis in Xinjiang increased from 17.59 per 100,000 to 36.45 per 100,000, representing a 107.22% rise compared with 2018⁽¹³⁾. Although the incidence declined to 28.95 per 100,000 in 2024, it remained higher than the 2018 level. As a Category I brucellosis-endemic area in China, Xinjiang has vast agricultural regions, and the Tianshan Mountains divide the territory into southern and northern parts, resulting in diverse topography and complex climatic conditions. These factors necessitate more precise monitoring and control measures for brucellosis in Xinjiang⁽¹⁴⁾.

In recent years, with the deepening of brucellosis research, Geographic Information System (GIS) technology has seen increasingly widespread application in this field due to its unique advantages⁽¹⁵⁾. Particularly in infectious disease studies, the spatio-temporal analytical capacity of GIS has become increasingly prominent, offering new

perspectives and technical tools for the surveillance and control of brucellosis⁽¹⁵⁾.

Through GIS-based analysis, surveillance data can be spatially visualized and quantitatively summarized, helping to reveal temporal variation, geographic heterogeneity, and clustering patterns of brucellosis. Evidence from existing studies has shown that GIS-based analyses of the spatio-temporal distribution of brucellosis in different regions of China not only help identify high-incidence areas but also provide a solid scientific basis for the development of targeted and practical prevention and control strategies⁽¹⁶⁾.

In Xinjiang, a region with highly variable and complex geographical and climatic conditions, often referred to as the “Three Mountains and Two Basins,” the application of Geographic Information System (GIS) technology for spatio-temporal analysis of brucellosis epidemics holds significant importance. Accurately identifying high-risk areas, hot spot dynamics, directional distribution patterns, and centroid displacement of brucellosis is important for formulating scientific and effective prevention and control measures. Based on brucellosis surveillance data from Xinjiang, this study conducts an in-depth analysis of spatial distribution differences at the county level, systematically examines the spatio-temporal characteristics and trends of the epidemic, and precisely identifies high-incidence areas. The findings aim to provide a sound theoretical foundation and practical guidance for the monitoring, early warning, risk assessment, and targeted prevention and control of brucellosis. Compared with previous national- or provincial-level studies, this study provides more geographically refined county-level evidence for Xinjiang by integrating temporal trend analysis, spatial

autocorrelation, hot spot analysis, weighted mean center movement, and standard deviational ellipse analysis over a recent seven-year period.

Materials and methods

Data and Sources

Human brucellosis surveillance data for 99 county-level spatial units (counties and county-level cities) in Xinjiang, China, from January 1, 2018 to December 31, 2024 were obtained from the China Information System for Disease Control and Prevention (CISDCP). Case ascertainment followed the Chinese national diagnostic standard for human brucellosis (WS 269–2019) used in the routine surveillance system⁽¹⁷⁾. According to this standard, diagnosis is based on a combination of epidemiological history, clinical manifestations, and laboratory evidence, and the surveillance records included in this study were based on reviewed cases entered into the CISDCP. Because the present study used routinely reported surveillance data, case classification was not further stratified by laboratory confirmation status in the spatial analysis. The study period covered seven complete calendar years, and annual data were extracted and organized according to epidemiological indicators, including incidence rate, number of reported cases, and regional distribution. Before analysis, the data were checked for completeness, geographic attribution, and logical consistency, and duplicate records were identified and removed. Regarding the Xinjiang Production and Construction Corps (XPCC), the XPCC headquarters was treated as an independent spatial unit in the analysis, whereas disease occurrence in subordinate units of the Corps was assigned to the corresponding county-level units based on their geographic locations.

County-level administrative boundary data were provided by the Xinjiang Institute of Geological Survey, detailing the county-level administrative divisions of Xinjiang. These boundary datasets were cross-checked with data from the Xinjiang Geographic Spatial Information Public Service Platform to verify positional consistency and ensure their suitability for spatial analysis.

Spatial Autocorrelation

In this study, Moran's I statistic was employed to analyze and characterize the spatial distribution patterns of brucellosis incidence in Xinjiang over the past seven years. Global Moran's I is calculated as follows:

$$I = \frac{n}{S_0} \cdot \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^n (x_i - \bar{x})^2}$$

Where n denotes the number of county-level units in the study area, x_i is the incidence rate in county i , $\bar{x}$ represents the mean incidence rate, and W_{ij} is the element of a row-standardized first-order queen contiguity spatial weights matrix, in which counties sharing either a common boundary or a common vertex are defined as neighbors.

The value of Moran's I ranges from -1 to 1 . At a significance level of $\alpha = 0.05$, values approaching 1 indicate positive spatial autocorrelation, values approaching -1 indicate negative spatial autocorrelation, and values near 0 suggest no overall spatial autocorrelation.

In addition, Local Moran's I was used to examine local spatial autocorrelation patterns of brucellosis incidence at the county level. Local Indicators of Spatial Association (LISA) clustering analysis was performed to identify four types of local spatial association: high-high (HH), high-low (HL), low-low (LL), and low-high (LH).

Furthermore, the Getis–Ord G_i^* statistic was used to detect spatial hot spots and cold spots of brucellosis incidence. The same row-standardized first-order queen contiguity spatial weights matrix was applied to the global Moran’s I, local Moran’s I, and Getis–Ord G_i^* analyses. Statistical significance was evaluated using the corresponding z-scores and p-values generated in ArcGIS 10.8, with $P < 0.05$ considered statistically significant. The G_i^* statistic is calculated as:

$$G_I = \frac{\sum_{j=1}^n w_{ij} x_j}{\sum_{j=1}^n x_j}$$

Where the variables have the same definitions as in the previous formula. At the significance level of $\alpha = 0.05$, a positive G_i^* value indicates a hot spot of brucellosis incidence, whereas a negative G_i^* value indicates a cold spot.

Standard Deviation Ellipse and Mean Center Shift Model

The brucellosis incidence database was integrated with the geographic coordinates of each county, and the mean center shift model (weighted mean center) was applied to calculate the spatial centroid of brucellosis incidence for different periods. The coordinates of the spatial centroid were calculated as follows:

$$\bar{X} = \frac{\sum w_i x_i}{\sum w_i} \quad \bar{Y} = \frac{\sum w_i y_i}{\sum w_i}$$

Where W_i represents the incidence rate of brucellosis in county i , and x_i and y_i are the longitude and latitude (or projected coordinates) of county i . The weighted mean center was used to describe temporal changes in the geographic center of annual brucellosis incidence.

The standard deviation ellipse (SDE) is a key tool in spatial statistics for quantifying the directional trends, dispersion, and shape characteristics of geographic features. The

ellipse is defined by its major and minor axes. Unlike Moran's I, which primarily detects spatial clustering, the SDE characterizes the directional distribution of spatial patterns. The major axis represents the dominant orientation of spatial distribution, while the minor axis reflects dispersion perpendicular to that orientation. A pronounced difference between the lengths of the two axes indicates strong spatial anisotropy, whereas nearly equal axis lengths suggest an approximately isotropic distribution. In this study, SDEs were generated using a 1-standard deviation (1-SD) ellipse based on the annual incidence rates.

Statistical Methods

Temporal trend in annual incidence was estimated using the Theil–Sen slope estimator and tested for significance using the Mann–Kendall trend test. Excel 2019 and SPSS 26.0 were used for data extraction, cleaning, checking, and descriptive organization of the surveillance dataset. OriginPro 2025 was used for temporal trend analysis and line chart visualization. ArcGIS 10.8 was used for county-level thematic mapping, global Moran's I analysis, local Moran's I (LISA) analysis, Getis–Ord Gi* hot spot analysis, weighted mean center analysis, and standard deviational ellipse analysis. For global Moran's I, local Moran's I, and Getis–Ord Gi* analyses, a row-standardized first-order queen contiguity spatial weights matrix was specified. Statistical significance was evaluated using the corresponding z-scores and p-values, with $P < 0.05$ considered statistically significant.

Results

Epidemiological Characteristics

From 2018 to 2024, a total of 40,326 human brucellosis cases were reported across 99 county-level units in Xinjiang, with annual incidence rates ranging from 12.34/100,000 in 2020 to 36.45/100,000 in 2023. Although the rate declined to 28.95/100,000 in 2024, it remained at a relatively high level. Clear seasonality was observed, with case numbers rising sharply during periods of livestock breeding and migration (Figure 1 and Figure 2).

Spatial distribution maps for 2018–2024 reveal pronounced geographic heterogeneity. According to the World Health Organization (WHO) definition, regions with an incidence $>50/100,000$ are classified as high-prevalence areas requiring urgent intervention. In 2024, 34.0% of counties exceeded this threshold, while 47.2% fell into the medium-prevalence category ($10/100,000$ – $50/100,000$), indicating a serious epidemiological situation.

Longitudinal analysis over seven years identified three persistent high-incidence belts:

1. **Northern slopes of the Tianshan Mountains** (e.g., Qitai County, Urumqi County), with a 7-year mean of 98.4/100,000;
2. **Ili River Valley** (e.g., Qapqal Xibe Autonomous County, Huocheng County), with a mean of 76.2/100,000;
3. **Altay Prefecture** (e.g., Buerjin County, Fuhai County), with a mean of 81.5/100,000.

These areas are characterized by intensive pastoralism, which may be associated with increased livestock-related exposure.

Wuqia County exhibited persistently high incidence, with a 7-year mean of

251.6/100,000. Two newly emerging high-risk counties—Aketao and Xinyuan—were identified. Aketao is adjacent to the high-incidence area of Wuqia County, with an annual incidence growth rate of 41.9%, while Xinyuan, located in the high-incidence area of the Ili River Valley, had a growth rate of 38.7%. Both counties transitioned from low- to medium-risk categories (Figure 3).

Spatial Autocorrelation Analysis

Global spatial autocorrelation analysis of annual human brucellosis incidence in Xinjiang from 2018 to 2024 showed positive Moran's I values in all study years, indicating an overall tendency toward spatial clustering. Statistically significant positive spatial autocorrelation was identified in 2018, 2019, 2022, 2023, and 2024 ($P < 0.05$), whereas the results for 2020 and 2021 were not statistically significant.

Overall, the spatial clustering of human brucellosis incidence in Xinjiang was generally weak but persisted in most years during the study period (Table 1).

Local spatial autocorrelation analysis indicated that high–high clusters were predominantly located in northern and eastern Xinjiang, while low–low clusters were mainly distributed in southern Xinjiang. Over the study period, the number of high–high clusters declined from 8 to 7, and low–low clusters decreased from 20 to 14, suggesting that some areas previously characterized by low–low clustering experienced increased incidence rates. Furthermore, the spatial center of high–high clusters shifted from northern Altay Prefecture toward eastern Altay, Changji Hui Autonomous Prefecture, and western Hami City (Figure 4).

Year	Moran's I	Z-score	p-value
2018	0.070	2.367	0.018
2019	0.079	2.536	0.011
2020	0.024	0.992	0.321
2021	0.028	1.104	0.270
2022	0.064	2.139	0.032
2023	0.066	2.202	0.028
2024	0.064	2.125	0.033

Table 1. Global Moran's I statistics for annual human brucellosis incidence in Xinjiang, 2018–2024.

Hot spot Analysis

Hot spot analysis of human brucellosis from 2018 to 2024 identified 24, 11, 14, 4, 13, 15, and 12 hot spot county-level units for each respective year. In 2018, 2019, 2020, 2023, and 2024, most hot spots were concentrated in Altay Prefecture and Changji Hui Autonomous Prefecture, accounting for 50.0%, 72.7%, 57.1%, 66.7%, and 66.7% of annual totals, respectively. In contrast, 2021 and 2022 hot spots were mainly located in Hami City in eastern Xinjiang, representing 75.0% and 33.3% of the annual totals.

Overall, human brucellosis in Xinjiang predominantly affected the northern and eastern regions, particularly Altay, Changji, and Hami. The number of hot spot counties peaked in 2018 and reached its lowest in 2021, with relatively stable fluctuations in other years. Spatially, hot spot locations varied across years, with concentration shifting

mainly between northern and eastern Xinjiang (Figure 5).

Standard Deviation Ellipse and Centroid Shift Analysis

Standard deviation ellipse analysis, based on annual incidence data of human brucellosis in Xinjiang, revealed that the ellipse's major and minor axes represent the directions of maximum and minimum spatial dispersion, respectively. In 2018, the ellipse area was at its smallest, indicating pronounced spatial clustering of incidence rates. In the subsequent years, the ellipse gradually expanded, reaching its maximum in 2021, indicating an increase in spatial dispersion during that period. From 2022 to 2023, the area contracted by 3.36% and 9.52%, respectively. However, in 2024, the area expanded again by 3.29% compared with 2023, suggesting a modest increase in spatial dispersion compared with 2023.

Centroid shift analysis illustrated the temporal movement of the epidemic's geographic center. In 2018, the weighted mean center was located south of Wusu City. In 2019, it shifted 72.94 km southwest to Xinyuan County. In 2020, it moved 38.21 km east within Xinyuan County, and in 2021, it shifted 63.8 km south to Hejing County. In 2022, the centroid moved 53.2 km west within Hejing County, followed by a 47.2 km northwest shift in 2023. In 2024, it shifted 23.5 km south. Overall, the weighted mean center moved a straight-line distance of 119.8 km during 2018–2024, from its 2018 position (84.68°E, 43.78°N) to its 2024 position (83.92°E, 42.90°N), with movements largely confined to northern Xinjiang and its adjacent areas (Figure 6).

Discussion

From 2018 to 2024, the annual incidence of human brucellosis in Xinjiang showed a

statistically significant overall upward trend according to Theil–Sen/Mann–Kendall analysis ($P < 0.01$), despite marked interannual fluctuations. Between 2018 and 2020, the incidence declined annually, with a cumulative decrease of 29.85%. However, from 2020 to 2023, the incidence increased markedly, with a cumulative increase of 195.38%. In 2024, the incidence dropped by 20.58% compared with the 2023 peak, although it remained at a relatively high level. Overall, the recent incidence pattern in Xinjiang was characterized by an overall upward trend accompanied by short-term fluctuations. This pattern may be related to several factors. First, the COVID-19 pandemic may have influenced the reported pattern of human brucellosis through multiple and potentially countervailing pathways. On the one hand, the diversion of public health resources and disruption of routine prevention and control activities may have affected the continuity of brucellosis surveillance, livestock vaccination, and related interventions. On the other hand, movement restrictions, reduced occupational contact, changes in healthcare-seeking behavior, and changes in reporting practices may also have altered exposure opportunities and case detection. Therefore, the net effect of the COVID-19 period on human brucellosis incidence in Xinjiang is likely to have been complex and should be interpreted cautiously^(18,19). Second, climatic and environmental changes may have influenced the environmental persistence of *Brucella* as well as livestock production activities and human exposure opportunities⁽²⁰⁾. In addition, structural adjustments in the livestock industry and increased interregional movement of livestock may also have contributed to the changing epidemic pattern, particularly in pastoral areas with relatively weaker prevention and control capacity⁽²¹⁾. These findings are

generally consistent with previous studies showing that human brucellosis in China is concentrated mainly in northern and pastoral regions, but this study further identifies county-level heterogeneity within Xinjiang^(6,22). Compared with broader national or provincial analyses, our results show that high-burden areas were persistently concentrated in northern Xinjiang, while hot spot locations varied between northern and eastern Xinjiang⁽⁶⁾. This finer spatial resolution may help distinguish stable high-risk areas from areas with changing local clustering patterns, thereby supporting more targeted and potentially more cost-effective surveillance and intervention strategies⁽²³⁾. Compared with studies from other provinces such as Hubei, the Xinjiang pattern appears to be more closely related to extensive pastoral production, large geographic distances, and seasonal livestock-related activities⁽²⁴⁾.

Global spatial autocorrelation analysis indicated that the annual incidence of human brucellosis in Xinjiang exhibited positive Moran's I values throughout the study period, suggesting an overall tendency toward spatial clustering. Statistically significant positive spatial autocorrelation was observed in 2018, 2019, 2022, 2023, and 2024, whereas the results for 2020 and 2021 were not statistically significant. Although the magnitude of Moran's I was relatively low, these findings indicate that the spatial aggregation of human brucellosis in Xinjiang was generally weak but present in most study years. This pattern may be related to the vast territory of Xinjiang, the heterogeneous distribution of pastoral areas, and regional differences in livestock production activities, transportation networks, and control capacity. Local spatial autocorrelation analysis further showed that northern and eastern Xinjiang were

characterized mainly by high–high (H–H) clusters, especially during the period following the increase in incidence after 2020, whereas southern Xinjiang was dominated by low–low (L–L) clusters with sporadic high–low (H–L) spatial outliers in adjacent areas. The persistent presence of H–H clusters in northern and eastern Xinjiang suggests a relatively concentrated local disease burden and stronger spatial similarity among neighboring county-level units^(25,26). In contrast, the predominance of L–L clusters in southern Xinjiang, together with scattered H–L clusters, reflects marked spatial heterogeneity in disease incidence across the region. The decrease in the number of L–L clusters between 2018 and 2024 may indicate that some previously low-incidence areas experienced a relative increase in epidemic risk; however, these local spatial patterns should be interpreted cautiously and should not be directly regarded as evidence of transmission direction or external introduction⁽²⁷⁾.

Hot spot analysis over the seven years showed that human brucellosis in Xinjiang was mainly concentrated in the northern regions of Altay and Changji, as well as the eastern Hami region. The distribution of hot spots suggested that hot spot locations varied across years, with a tendency for concentration to shift between northern and eastern Xinjiang, which may be related to changes in livestock movement, exposure patterns, and local prevention and control conditions^(28,29). Between 2018 and 2024, the epidemic center shifted among three northern locations, namely Wusu City, Xinyuan County, and Hejing County. Although the weighted mean center showed geographic displacement over time, it remained within northern Xinjiang throughout the study period. The standard deviational ellipse was oriented northeast–southwest, and its area fluctuated

over time with an overall tendency toward expansion, indicating changes in the spatial dispersion and directional distribution of incidence. Taken together, these findings suggest that the incidence burden of human brucellosis remained higher in northern and eastern Xinjiang than in the south, while the geographic distribution pattern changed to some extent over time⁽³⁰⁾.

The occurrence of human brucellosis cannot be understood solely from either the temporal or the spatial dimension. Spatiotemporal analysis makes it possible to examine temporal variation together with geographic heterogeneity, thereby helping to identify areas with relatively high disease burden and changing clustering patterns⁽³¹⁾. By taking counties and county-level cities as the analytical units, prevention and control measures can be more precisely aligned with local epidemiological conditions. However, the results of spatiotemporal analysis should mainly be interpreted as evidence of spatial clustering, hot spot concentration, and geographic displacement, rather than as direct evidence of transmission pathways or etiological mechanisms⁽³²⁾. At the clinical level, MRI and, in selected focal cases, PET/CT may assist the differential diagnosis and evaluation of focal complications of brucellosis, particularly spinal or neurological involvement, although detailed discussion of these imaging approaches was beyond the scope of the present ecological analysis^(33,34).

Xinjiang is vast, accounting for one-sixth of China's land area. It is also the second-largest pastoral region in China, with rangelands making up 26.8% of the nation's usable grassland area. The complex geography, often described as the "Three Mountains and Two Basins," may influence the spatial organization of pastoral

production, river-valley settlement, seasonal grazing, and livestock movement. Northern Xinjiang's higher incidence compared with the south may be related to the concentration of extensive pastoral zones in the northern Tianshan foothills, Ili River Valley, and Altay Prefecture, where livestock production and occupational exposure are more prominent⁽³⁵⁾. In pastoral areas, sheep and goats are important livestock species, and human exposure may increase during lambing or kidding, slaughtering, handling of aborted materials, and contact with contaminated animal products. In addition, climatic differences between northern and southern Xinjiang may influence the environmental persistence of *Brucella* and the intensity of livestock-related exposure, thereby affecting the regional distribution of human brucellosis⁽³⁶⁾. However, animal infection burden, species-specific livestock population, and movement data were not available in this study, and these geographic and livestock-related interpretations should therefore be viewed as hypotheses requiring further validation.

Therefore, brucellosis control in Xinjiang should be aligned with the observed clustering patterns and regional heterogeneity of the epidemic, and differentiated prevention and control strategies should be implemented accordingly. Given the clear spring–summer seasonality, interventions such as livestock vaccination, occupational protection training, health education, and diagnostic preparedness may be more efficient if implemented before the high-incidence season. Prioritizing persistent hot spot counties and high-burden pastoral areas may also reduce unnecessary resource use in consistently low-incidence areas. In northern Xinjiang, where the burden remains relatively high, greater resource investment is needed. Priority measures include

strengthening livestock vaccination and quarantine, standardizing occupational protection practices for those engaged in animal husbandry and livestock product processing, reducing direct contact with potentially infected animal tissues and secretions, and improving the clinical capacity for early diagnosis and standardized treatment⁽³⁷⁾. Although southern Xinjiang generally remained at a relatively lower incidence level, continued attention should be paid to areas showing changes in local clustering patterns or relative increases in incidence. In addition, targeted public health education should be strengthened across Xinjiang to improve public awareness and prevention capacity⁽³⁸⁾. Given the regional heterogeneity and temporal variability of brucellosis incidence, optimizing medical resource allocation and identifying key monitoring areas and populations are important for improving prevention and control efficiency and reducing disease burden⁽³⁹⁾.

This study has several limitations. First, as the analysis was based on routine passive surveillance data, underreporting, delayed reporting, and regional or temporal variation in case detection and reporting quality could not be fully excluded. Second, this was an ecological study conducted at the county level, and ecological bias may exist; therefore, the findings should not be directly interpreted at the individual level. Third, the analysis did not further incorporate animal infection burden, livestock vaccination coverage, livestock movement, occupational exposure, socioeconomic conditions, or healthcare accessibility, which may have contributed to the observed spatial heterogeneity. Finally, although spatial autocorrelation, hot spot analysis, weighted mean center analysis, and standard deviational ellipse analysis are useful for describing clustering patterns, hot

spot concentration, and geographic displacement, these results should not be interpreted as direct evidence of transmission pathways or causal mechanisms. In addition, the queen-contiguity Moran's I framework defines spatial relationships based on adjacency and may not fully capture other pathways relevant to brucellosis risk, such as roads, mountain passes, river valleys, livestock trade routes, seasonal pasture movement, or transboundary herder-driven movement. Future studies should incorporate broader explanatory variables and use finer spatial scales to further clarify the epidemiological patterns and determinants of human brucellosis.

Conclusion

This study employed GIS technology to systematically analyze the spatiotemporal dynamics of human brucellosis incidence in Xinjiang from 2018 to 2024. The results revealed an overall upward trend over the seven-year period, with a marked surge from 2020 to 2023 (cumulative increase of 195.38%), followed by a 20.58% decline in 2024 that nevertheless remained at a high level. Spatial autocorrelation analysis indicated that clustering patterns varied by year, with persistent high-high (H-H) clusters in Northern and Eastern Xinjiang, while Southern Xinjiang was dominated by low-low (L-L) clusters accompanied by sporadic high-low (H-L) units in adjacent areas. Hot spot analysis showed that hot spot locations varied across years, but remained mainly concentrated in Northern and Eastern Xinjiang. Weighted mean center analysis indicated geographic displacement of the epidemic center over time, while the standard deviational ellipse suggested a relatively stable northeast-southwest directional distribution pattern. Overall, the burden of human brucellosis remained higher in

Northern and Eastern Xinjiang than in the south.

Declarations

Ethics statement

This study was based on secondary analysis of de-identified surveillance data obtained from the National Notifiable Infectious Disease Reporting System (NNIDRS) of China. No individual participants were contacted, and no personally identifiable information was used. Therefore, formal ethical approval and informed consent were not required for this study.

Consent for publication

Not applicable

Data availability statement

The data supporting the findings of this study are available from the Xinjiang Uygur Autonomous Region Center for Disease Control and Prevention. However, restrictions apply to the availability of these data, which were used under license for the current study and are therefore not publicly available. Data may be obtained from the authors upon reasonable request and with permission from the Xinjiang Uygur Autonomous Region Center for Disease Control and Prevention.

Authors' contributions

All authors contributed to the study conception, data analysis, and manuscript preparation, and all approved the final manuscript.

Conflict of interest statement

The authors declare no competing interests.

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Figure legend

Figure 1. Incidence Rate and Moving Average line graph of human brucellosis incidence from 2018 to 2024 in Xinjiang.

The solid line represents the annual reported incidence rate per 100,000 population, while the dashed line indicates the 3-year moving average used to smooth short-term fluctuations. The incidence generally increased during the study period, peaked in 2023, and declined in 2024 while remaining at a relatively high level.

Figure 2. Monthly number of reported human brucellosis cases from 2018 to 2024 in Xinjiang.

The heat map shows clear seasonal variation, with higher case numbers generally observed from March to July and lower numbers in winter. Monthly case counts increased markedly before peaking

in 2023 and declined in 2024.

Figure 3. The thematic maps of human brucellosis incidence from 2018 to 2024 in Xinjiang.

Each panel represents the annual incidence rate per 100,000 population at the county level. Warmer colors indicate higher incidence, while cooler colors indicate lower incidence. The maps reveal a consistent concentration of high-incidence areas in northern Xinjiang, particularly along the northern slopes of the Tianshan Mountains, the Ili River Valley, and the Altay region.

Figure 4. The LISA cluster maps of human brucellosis incidence from 2018 to 2024 in Xinjiang.

Each panel shows county-level clustering patterns of incidence rates. Red areas represent *high–high* clusters, indicating counties with high incidence surrounded by high-incidence neighbors. Blue areas represent *low–low* clusters, indicating counties with consistently low incidence adjacent to other low-incidence areas. Light red denotes *low–high* clusters, and light blue denotes *high–low* clusters, reflecting spatial outliers. Grey areas indicate non-significant clustering. The maps reveal persistent *high–high* clusters in northern Xinjiang, particularly in the Ili River Valley and the Altay region, with spatial variation across years.

Figure 5. Hot spots of human brucellosis incidence in Xinjiang, 2018–2024.

The maps display statistically significant hot and cold spots of human brucellosis incidence identified using the Getis–Ord G_i^* statistic ($p < 0.05$). Red areas indicate statistically significant hot spots (high incidence clustered with high-incidence neighbors), while blue areas represent cold spots (low incidence clustered with low-incidence neighbors). Grey areas denote non-significant regions. Hot spots were mainly concentrated in northern and eastern Xinjiang, although their locations and extent varied across years.

Figure 6. Weighted mean center and standard deviational ellipse of human brucellosis incidence in

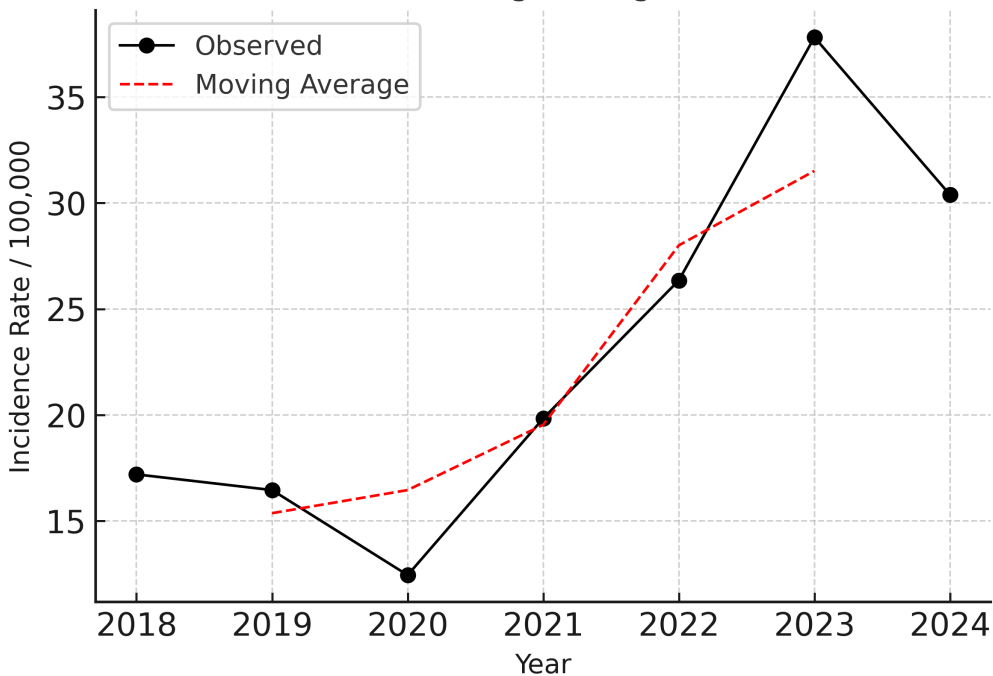
Xinjiang, 2018–2024.

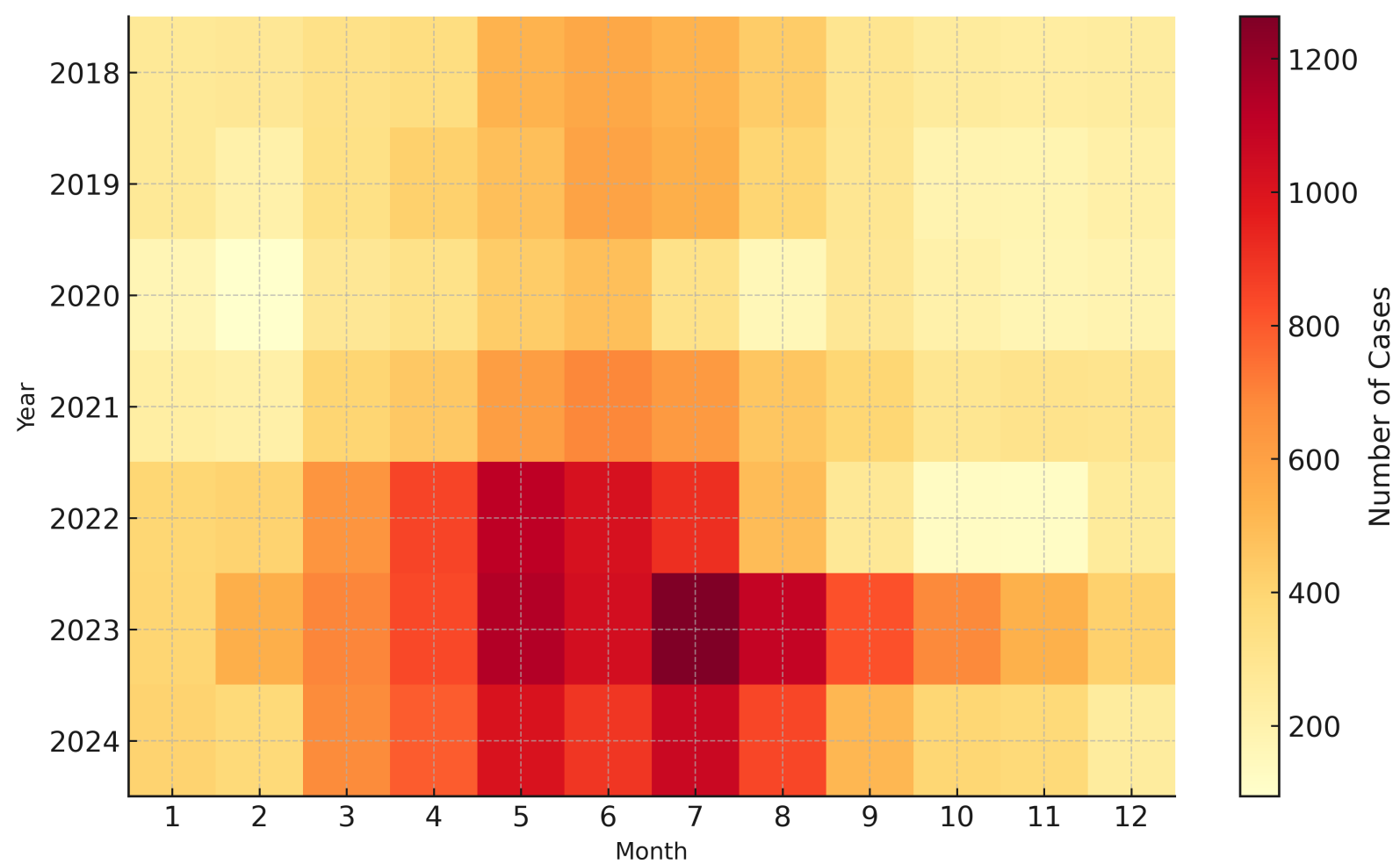
The ellipses represent the overall spatial distribution, directional tendency, and dispersion of annual

incidence, while the centroid indicates the weighted mean center of incidence. Temporal changes in

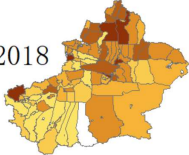
the centroid reflect shifts in the geographic focus of the epidemic.

Incidence Rate and Moving Average

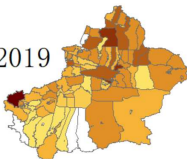




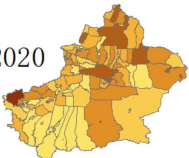
2018



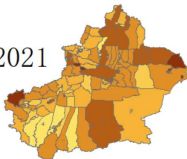
2019



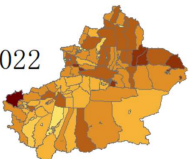
2020



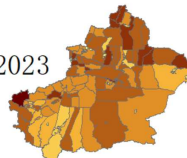
2021



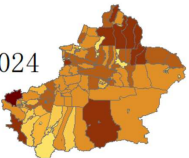
2022



2023

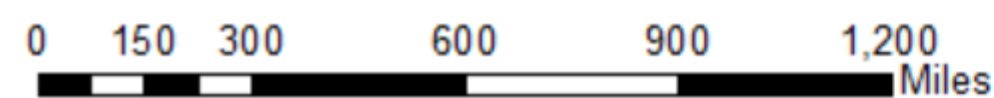
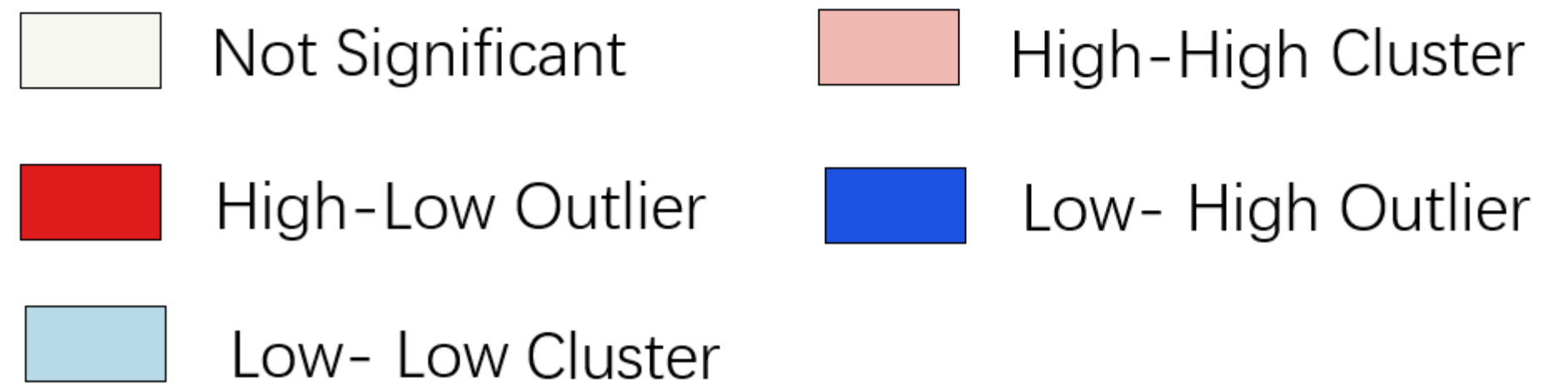
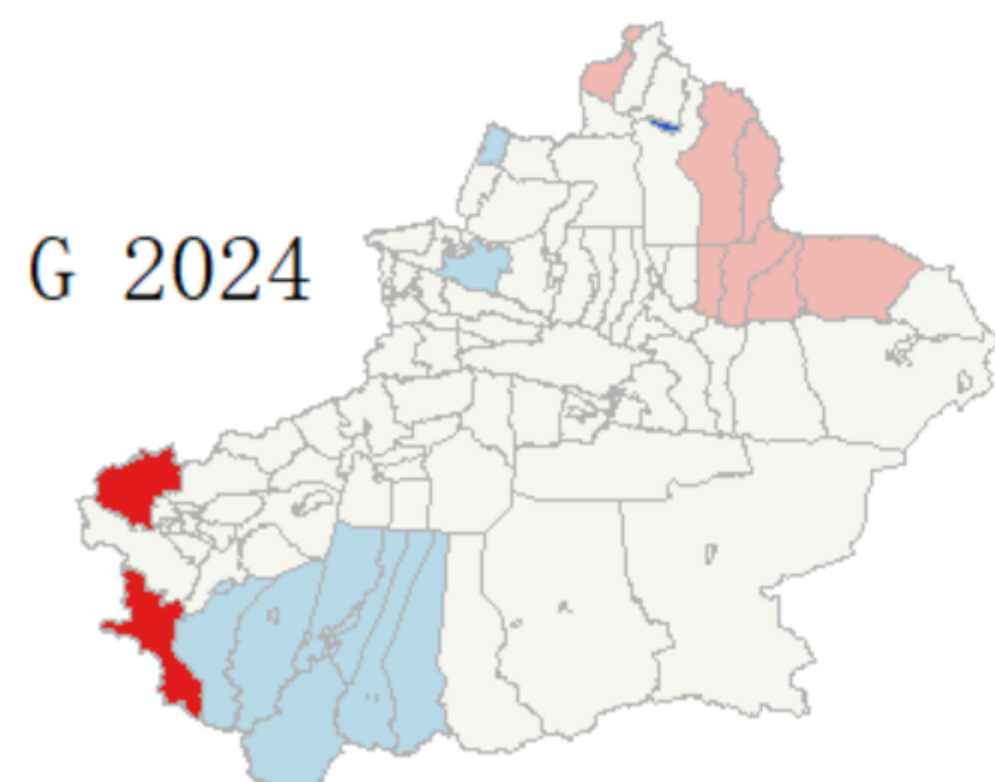
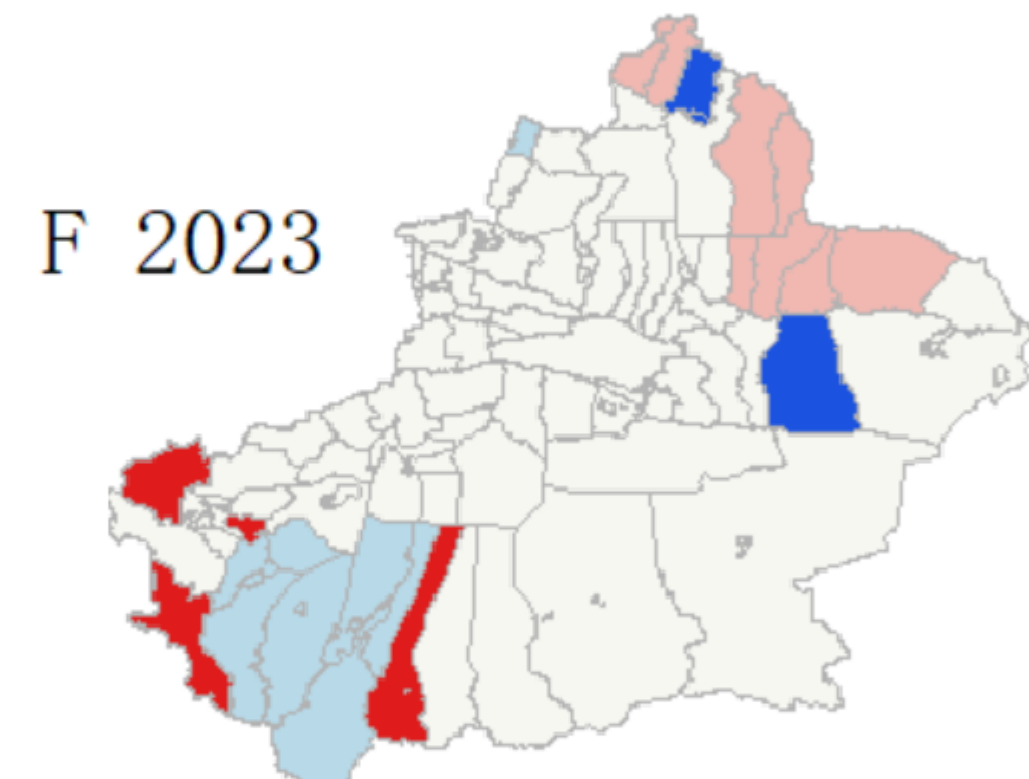
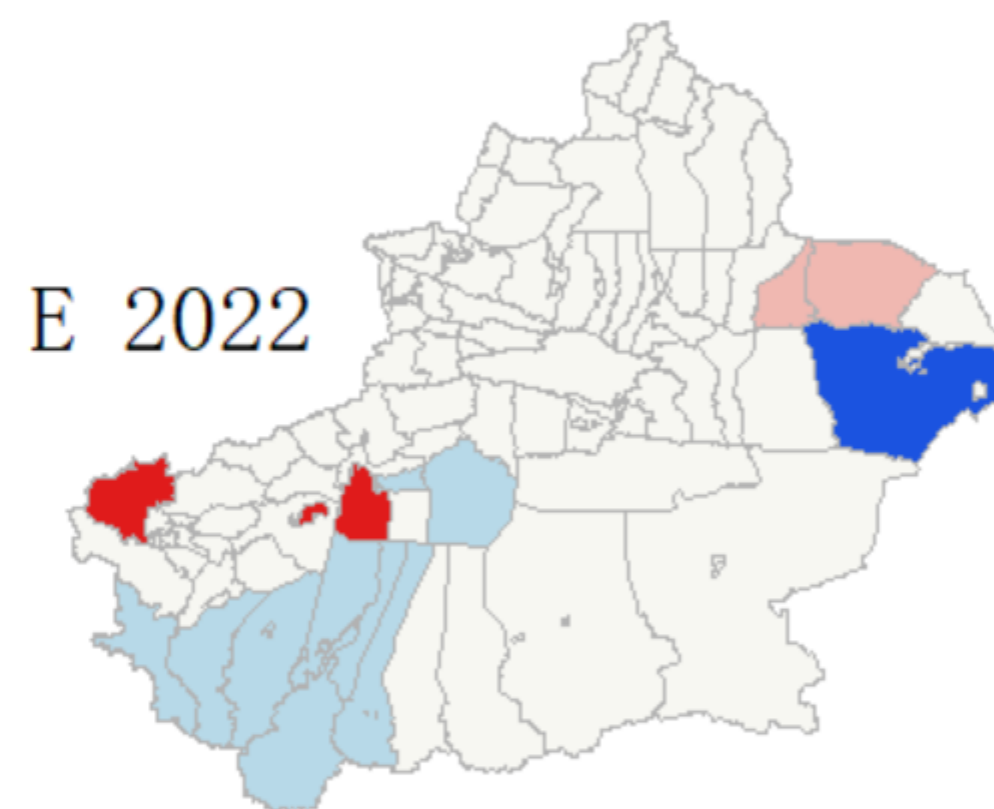
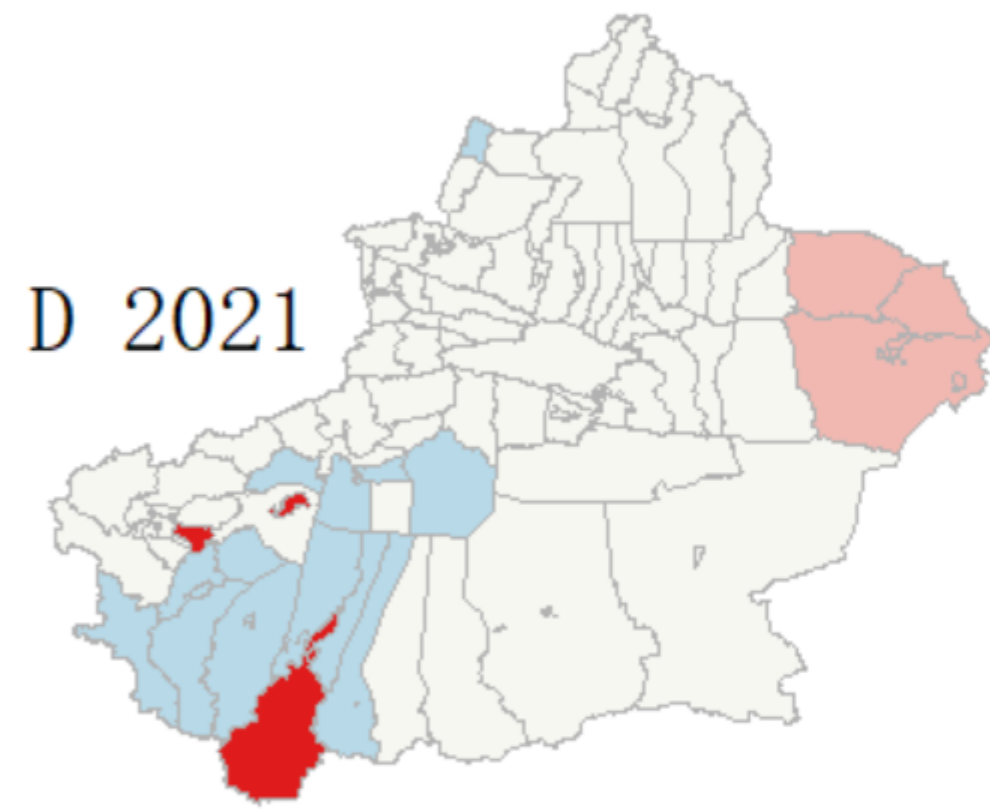
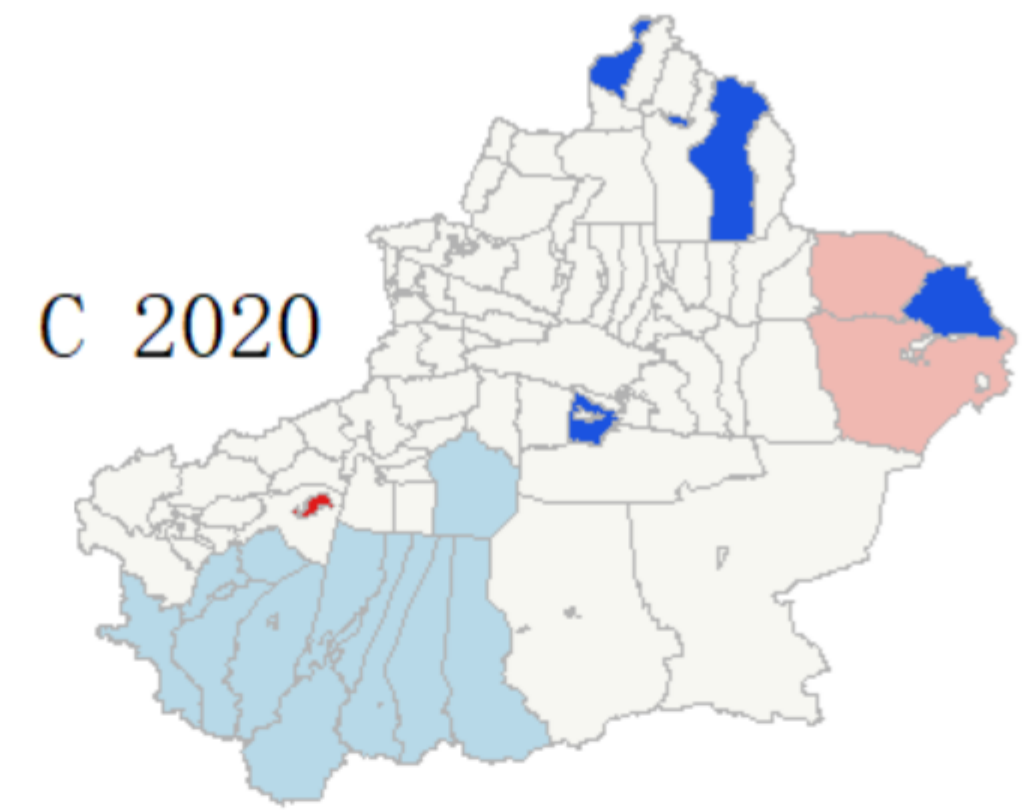
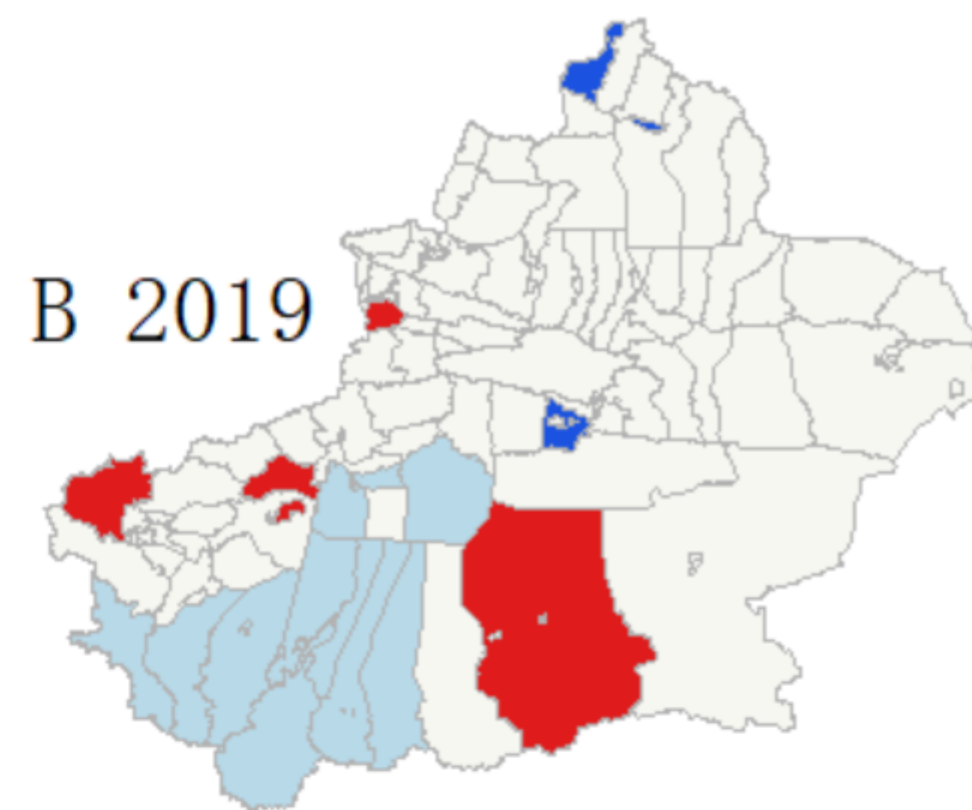
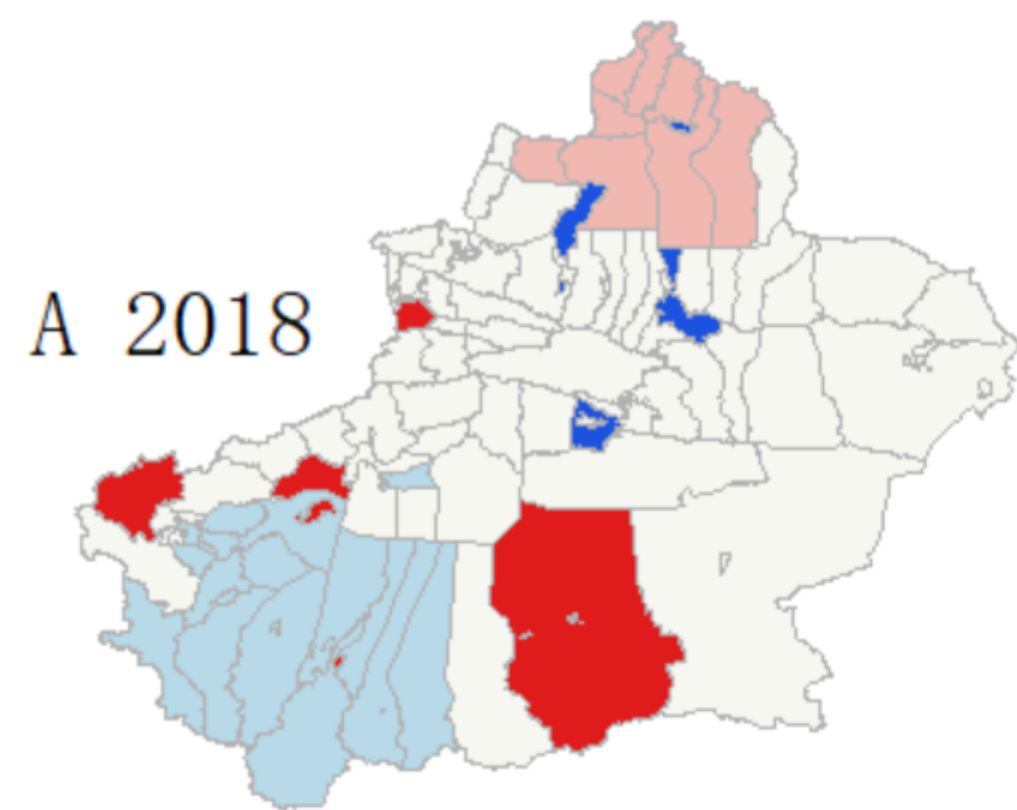


2024

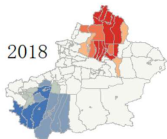


Incidence rate/100000

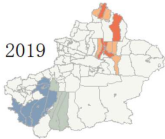




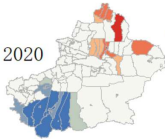
A 2018



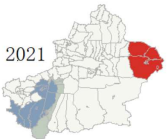
B 2019



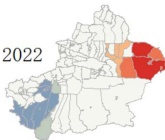
C 2020



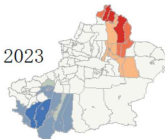
D 2021



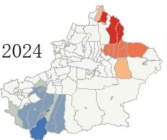
E 2022



F 2023



G 2024



Not Significant

Cold Spot – 99% Confidence

Cold Spot – 95% Confidence

Cold Spot – 90% Confidence

Hot Spot – 99% Confidence

Hot Spot – 95% Confidence

Hot Spot – 90% Confidence

0 150 300 600 900 1,200
Mile



